# Analysis of Barriers for development of Green Hydrogen in United Arab Emirates (UAE)

*Barrier Analysis using a combination of Best-Worst Method (BWM) and Decision-making trial and evaluation laboratory (DEMATEL) technique*

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by

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# *EXECUTIVE SUMMARY*

The Gulf Cooperation Council (GCC) countries have one of the highest annual energy consumption per capita and rank within the top 10 countries with highest $CO_2$ emissions. All of the countries have low levels of renewable energy share in the total energy consumption. Among these countries, UAE has been relatively proactive in promoting the use of renewable energy. The UAE's Energy Strategy 2050 aims at achieving 50% of clean energy share in the total energy consumption by 2050. However, this strategy published by the government does not mention anything about the development of green hydrogen. On the other hand, several articles and reports have highlighted the large potential for the development of green hydrogen in UAE along with other GCC countries. However, these studies do not address the potential barriers that UAE might face in the development of a green hydrogen supply chain. Therefore, this thesis aims to identify the barriers to the development of green hydrogen in UAE and provide suggestions to overcome them based on the interrelationships and priorities explored in this research. The following research questions are asked: ***"What are the barriers for large-scale development of green hydrogen in UAE?"*** and ***"What are the most influential barriers to the development and what interrelationships exist between them?"***

In order to identify the barriers to the growth of green hydrogen in UAE, a combination of literature study and expert interviews was implemented. A total of 20 barriers are identified categorised in technical, economic, institutional and social barrier groups. Next, a methodology is chosen which helps us map the interrelationships between the barriers and identify the most important barriers to be tackled first. A combination of two methods is used in tandem to achieve the desired results. A combination of DEMATEL and BWM, two multi-criteria decision methods is used. This methodology is implemented to obtain two vital pieces of information; firstly, DEMATEL provides information on the interrelationships of barriers and identifies the best and worst criteria for implementing BWM. Secondly, the barriers are ranked on their influence on the system through BWM which provides us the order of priority the barriers should be tackled. Another novelty of this research is that the information derived from DEMATEL helps in filtering out the criteria and takes into consideration the cause-and-effect groups while choosing the best and worst criteria for implementing BWM, thus making the process convenient and reliable.

After the application of this methodology to the identified 20 barriers, we are able to highlight the interrelationships that exist between the barriers and the order of priority they should be tackled in for successful development of green hydrogen in UAE. "Lack of legislature for hydrogen", "Preference towards fossil fuels", "High initial costs" and "Lack of incentives, tax breaks and subsidies" are found to be most critical barriers that need immediate attention. "High storage, transmission and distribution", "Lack of privatization in energy sector", "Lack

of awareness in society" and "Safety issues of hydrogen" are other important problems that need to be tackled. Next, recommendations are provided for overcoming these barriers considering the interrelationships established.

Solutions are proposed to solve these barriers in the form of policy requirements, pilot project schemes, addition of courses on the subjects of renewable energy in curriculums and other methods which best tackle the specific barrier in question. For example, to overcome the lack of legislature for hydrogen, suggestions for addressing all the barriers it affects; these would include promoting installation of renewable energy, provision of grants/funds for installation of green hydrogen production facilities, establishing subsidy schemes or incentives and promote adoption of alternative sources of energy and move away from fossil fuels. Preference towards fossil fuels can be tackled by promoting the applications of hydrogen alongside subsidies for using them, phasing out subsidies for use of fossil fuels and implementation of carbon taxes to encourage the use of hydrogen and implementing small scale demonstration of hydrogen technology in applications like public transport. Similarly, solutions are provided for all barriers. Due to the complex interrelated nature of the barriers, some solutions alleviate other barriers automatically.

This study identifies the barriers to green hydrogen development in UAE, provides the order of priority to tackle the barriers and provides recommendations on overcoming the barriers. The outcomes of this study can aid the policymakers in UAE in formulation of a hydrogen strategy. Additionally, the methodology of DEMATEL-BWM used in this research can be implemented to other topics of energy transition. This study also provides a foundation for analysing further analysing the hydrogen economy in UAE. Finally, the limitations of this study are highlighted and recommendations for future research are provided.

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# Chapter 1: Introduction

One of the most significant challenges in the 21st century is providing everyone access to healthy and clean energy sources. Use of energy has been the backbone to the evolution of humankind, from discovering fire in the Stone Age to harnessing the highly concentrated forms of energy within the fossil fuels in the nineteenth and twentieth century. This use of fossil fuels provided the driving force behind the industrial revolution resulting in an unprecedented rise in productivity across the planet. However, there has been an increasing awareness that the current world's energy systems must be drastically altered to meet are long-term energy needs.

In the past decade there has been a great influx of renewables in the energy mix worldwide. This is predominantly due to lowering costs, growth promoting policies, awareness about climate change and global warming. In the Paris Agreement of 2015, 195 member countries pledged to reduce the carbon emissions and keep the average global temperature increase below 2˚C above the pre-industrial levels (UNFCCC, 2015)

The Gulf Cooperation Council (GCC) countries consists of Bahrain, Kuwait, Oman, Qatar, Kingdom of Saudi Arabia (KSA), and the United Arab Emirates (UAE). These group of countries have an energy consumption per capita from 5340 kWh to 17610 kWh, which is higher than the global average of 2728 kWh and rank within top 10 countries with highest CO2 emissions (Al-Badi, 2019; Statista, 2019a). This is mainly due to large fossil-fuel reserves, economic prosperity, and high industrial activities. KSA is the second-largest oil producer, Qatar is the largest exporter of LNG in the world, and UAE has the sixth-largest oil and natural gas reserves (Salim, 2020).

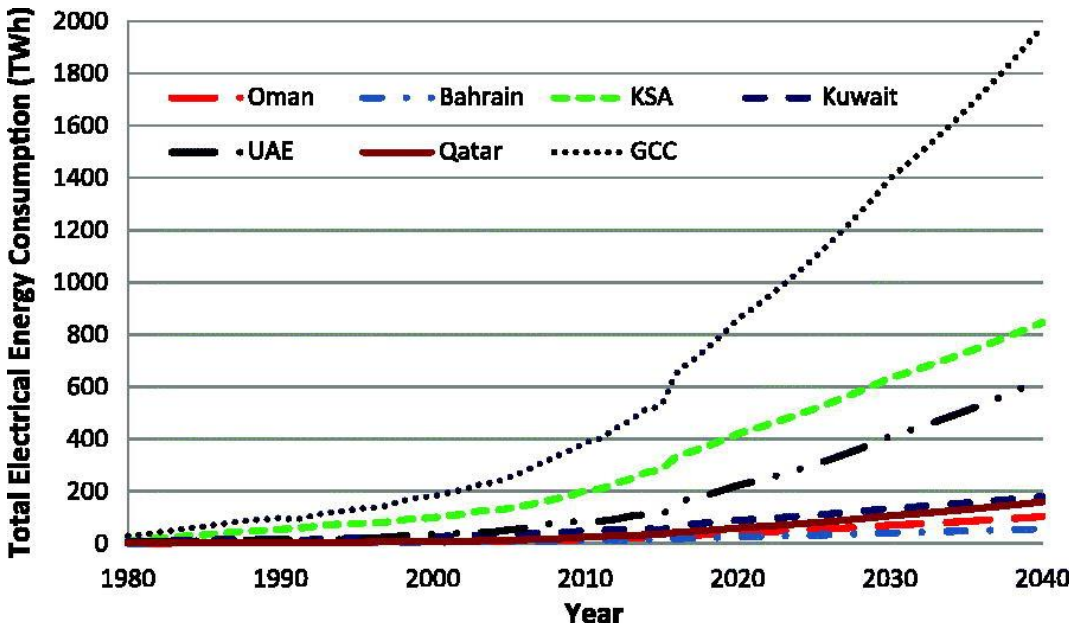


*Figure 1 Electrical energy consumption in GCC, 1980-2040 (Al-Badi, 2019)*

These hydrocarbon reserves have played a major role in the region's socio-economic development and led to exponential immigration rates, hence the rise in demand for energy. Figure 1 presents the increasing electrical energy consumption from 1980-2040; with KSA and UAE having almost twice the amount of the other GCC countries.

It would not be an exaggeration to say that the countries in GCC have developed from small cities to huge metropolises courtesy of discovery of oil and gas reserves in the region during the first half of the 20th century (Whitaker, 2021). Due to the abundance of these reserves, the electricity is almost 100% generated from oil and gas and is heavily subsidised by the government (Abdmouleh, Alammari, & Gastli, 2015). This has been a barrier to the development of renewable energy sector and implementation of energy efficiency (Groissböck, 2018).

In recent times, the term of "Hydrogen economy" has been gaining attention in green energy research circles. Blue hydrogen is viewed as a "bridge" in transitioning to a green hydrogen economy (Calabrese, 2021). Blue hydrogen is derived from steam reforming process where the emissions are captured and stored underground, whilst green hydrogen is a clean form of hydrogen that is produced using electricity generated by renewable sources like solar PV and wind energy. The GCC region is also keen on diversifying its economy through the production of green hydrogen by capitalizing on the availability of existing oil and gas infrastructure and cheap renewable generation (Chance, 2021).

However, in spite of the indicated potential and interest for development of green hydrogen, the region currently has very low levels of installed capacity of renewable energy generation and has not published any strategies for development of green hydrogen. The lower installed capacity affects the prospects of utilizing electricity generated from renewable energy sources to generate green hydrogen and the lack of a planned strategy does not give a proper direction for the successful development of green hydrogen in these countries. This thesis would be aimed at investigating barriers like these for the development of green hydrogen in the case of United Arab Emirates.

In the first section of this introduction, we will define the problem being researched and highlighting the existing knowledge gaps. Secondly, the objectives of this research would be established. The next section will define the main research questions and sub-questions. The fourth section would define the scope of the research. The fifth section will briefly explain the research methods implemented and the methods implemented for collection of relevant data. Next, the relevance of this research is explained and finally an outline of thesis will be provided.

## 1.1 Problem Definition

All GCC countries are signatories of the Paris Agreement in 2015 and were required to submit 'Intended Nationally Determined Contributions (INDCs) Reports' proposing their climate plans. These INDCs are indicative that the GCC countries have targets to add renewable energy to the energy supply mix in the future. The United Arab Emirates has ‘ambitious’ plans to limit emissions and increase the share of clean energy in the energy mix over a timeframe to 2050 (The United Arab Emirates, 2015). Details for Electricity generation mix alongside specific GHG reduction, energy efficiency and renewable electricity generation targets for all GCC countries are listed in Table 1.

| | **Electricity Generation (PJ)2018** | | | **Renewable Energy Targets** |
|---|---|---|---|---|
| | **Non-Renewable electricity** | **Renewable electricity** | | |
| | | **Solar** | **Wind** | |
| **Bahrain** | 114.57 | 0.03 | 0.004 | • 5% renewable energy by 2025 and 10% by 2035.<br>• Increase energy efficiency by 6% by 2025. |
| **Kuwait** | 266.57 | 0.26 | 0.06 | • 15 % renewable electricity by 2030.<br>• Increase energy efficiency by 30% by 2030. |
| **Oman** | 135.60 | 0.06 | - | • 10% electricity from renewable sources by 2025.<br>• 2% reduction in emissions by 2030. |
| **Qatar** | 172.49 | 0.03 | - | • 200-500 MW Solar by 2020<br>• 8% per capita electricity consumption by 2022. |
| **Saudi Arabia** | 1291.87 | 0.77 | 0.02 | • 9.5 GW renewable energy by 2023.<br>• 30% renewable energy by 2030.<br>• Increase energy efficiency by 8% by 2021.<br>• 14% peak demand reduction by 2021. |
| **UAE** | 484.90 | 4.71 | - | • Energy mix consist of 27% ‘clean energy’ by 2021.<br>• 44% of renewable energy capacity by 2050.<br>• Increase energy efficiency by 40% by 2050. |

*Table 1 Renewable electricity generation data (2018) & energy targets within GCC countries (IRENA, 2019a; Welfle, 2021)*

Amongst all the GCC countries, Kingdom of Saudi Arabia and United Arab Emirates have the highest electricity generation/consumption and most ambitious renewable energy development plans with respect to the current levels of generation. Although these countries have ambitious plans for the upcoming years, critics argue if they are mere distractions to prolong business-as-usual period continue their dependence on ONGC (Whitaker, 2021).

Despite of being the wealthier petrostates possessing significant resources for renewable energy deployment, they have been faced with barriers in implementations (Coffin, 2021). With oil demand projected to peak in 2026, economy of UAE would be impacted considering majority revenue generation is attributed to fossil fuel reserves (IEA, 2021). Coffin (2021) highlighted the potential revenue shortfall for petrostates under a lower demand scenario VS last five years in Figure 2

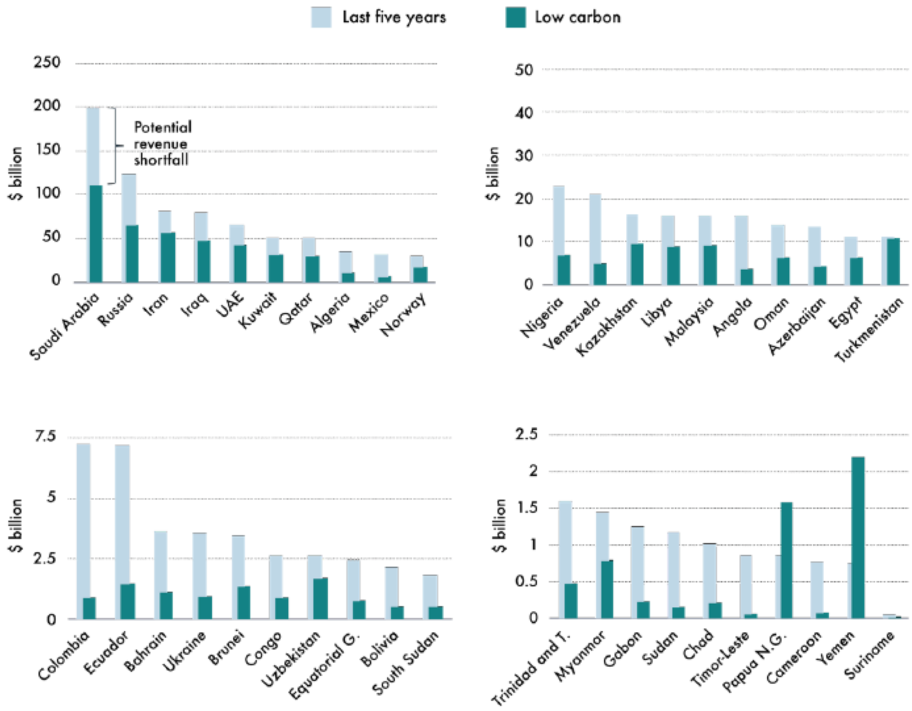


*Figure 2 Revenue shortfall vs last five years revenue of petrostates (Coffin, 2021)*

From Figure 2 we can see that UAE has one of the largest shortfalls amongst GCC countries at 44% ($88 Billion) and 34% ($23.12 Billion) respectively (Coffin, 2021). One of the ways to hedge these countries against shortfalls would be 'economic diversification' achieved through investing into international tourism and renewable energy (Ferris, 2021). The domestic oil consumption is projected to exceed the exports which would jeopardizes economic growth, therefore reduction in own consumption would prove beneficial (Al-Maamary, M.S. Kazem, & A. Chaichan, 2017).

Green hydrogen has a wide range of applications from petroleum refining to fertilizer production and is being experimented to decarbonize energy-intensive industries of heavy road freight, shipping, aviation, chemicals, cement and iron and steel manufacturing (Calabrese, 2021). Currently, only 0.1% of global hydrogen production is green; hindered by the costs of using renewable energy and carbon storage for the process of electrolysis (IEA, 2019; Zapantis, 2021). This ends up making green hydrogen 2-3 times more expensive than the blue hydrogen, produced from fossil fuels in conjuncture with carbon capture and storage (CCS) (IRENA, 2020).

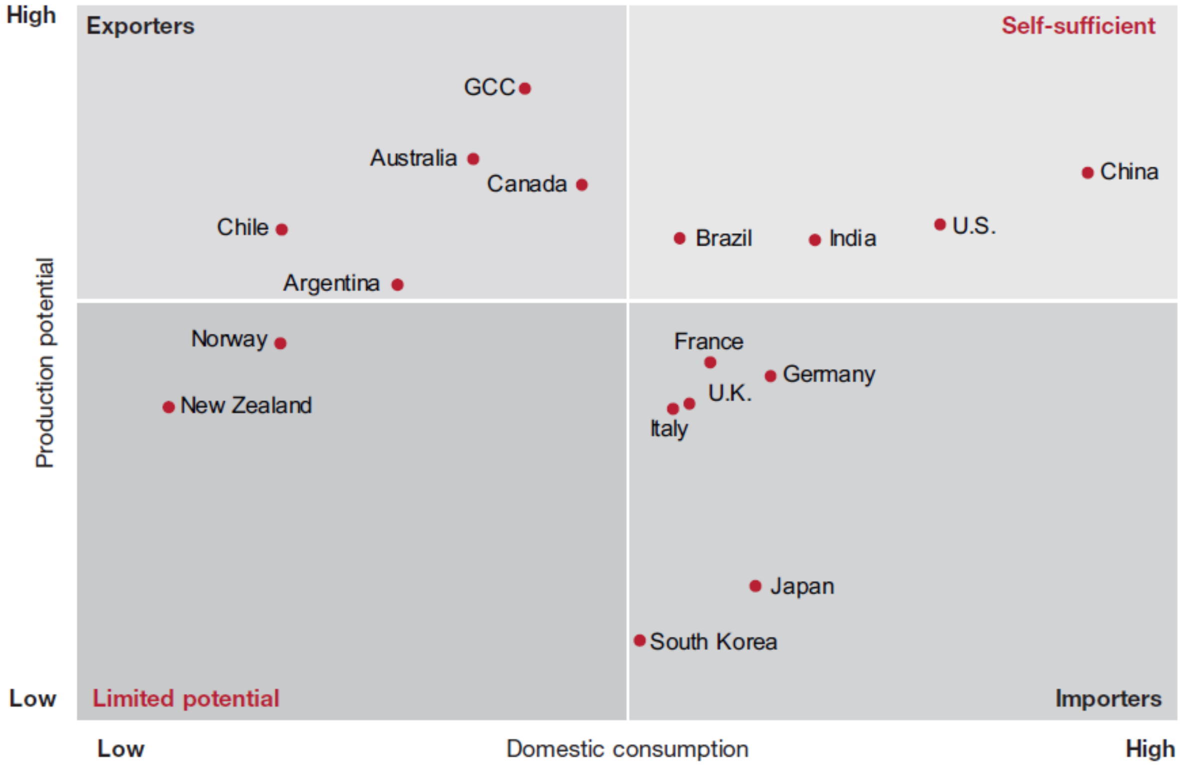


*Figure 3 Hydrogen (Blue & Green) export potential (Dr. Kombargi, Dr. Elborai, Dr. Anouti, & Hage, 2020)*

Figure 3 displays a promising opportunity for GCC countries thanks to potential of low-cost renewable energy due to high solar exposures, favourable geology in large areas of barren land, energy-intensive industries clustered with existing hydrogen production facilities (mainly in UAE and KSA), significant CO2 storage capacity (KSA, Kuwait and UAE), abundance of salt water for the electrolysis process and well-developed infrastructure such as natural gas (Dr. Kombargi et al., 2020; Netherlands Enterprise Agency, 2020). Green hydrogen export market is projected to be worth US$300 billion yearly by 2050 and the GCC countries have unique advantages over the competition (Dr. Koegler & Thomas, 2020). Promoting investment in utility-scale solar farms is a critical facilitator to lead these countries to lay the foundation for production of green hydrogen and continue their influence over the energy market. The current research on green hydrogen in UAE indicates the high potential for its implementation, however, the transition to a hydrogen-economy could be a complex problem.

*Knowledge Gap 1: A lot of focus has been attributed to the potential for UAE to emerge as a key green hydrogen producer but the road to achieving that is unknown. Identifying and addressing the barriers to development of green hydrogen in United Arab Emirates is one of the missing components.*

A barrier analysis is performed to identify the bottlenecks and problems faced by any industry to its progress, renewable energy industry is no exception and therefore has barriers of its own. The countries of GCC, especially UAE plays a central role in the current energy system and potentially in future energy systems as well through the development of power-to-hydrogen technologies. Researchers like (Patlitzianas, Doukas, & Psarras, 2006) were one of the first studying the challenges and efforts undertaken for the development of renewable energy in the GCC after their accession to Kyoto Protocol in 2005; interviews with “renewable energy” actors was the chosen methodology to assess the countries performance with respect to the identified barriers. (Lilliestam & Patt, 2015) used a combination of literature analysis and interviews to determine the barriers to large scale diffusion of renewable energy in GCC; the paper implemented the Likert scale to quantify the responses of the survey to calculate a mean value for the factors of case for renewables in GCC, barriers to RE investments, risks associated with RE investments, most impactful policies and incentives and role of RE targets and roadmaps. This alongside literature analysis is used to find the important barriers and make recommendations to government to smoothen the adoption of renewables.

Most studies focus on identification of barriers, but the development of a technology is a more complex problem with various barrier factors working together and not independently. The interrelationships among barriers are often neglected when barriers to RES adoption are studied, leading to the absence of cause-and-effect groups (Tseng, Ardaniah, Sujanto, Fujii, & Lim, 2021). Mapping the mutual relationships between barriers is important as they not only influence the technology but also each other. These inter-relations are critical for the policymakers to understand to successfully complete energy transition (Dhawale, 2019). An example of interactions between different barriers is as follows, a nascent technology used for transporting/storing the hydrogen will not only increase the cost of infrastructure but also discourage the investors for adoption. Similarly, selection of location for such a facility would impact the initial capital cost and operation and maintenance costs (Xu, Wu, & Dai, 2020).

*Knowledge Gap 2: Study of interrelationships between barriers to green hydrogen production has not been performed previously. Creation of cause-effect groups for the case of United Arab Emirates will provide more insights in the interrelationships of barriers.*

Countries with similar conditions like UAE have also been studied for identification of barriers. These include petrostates like Iran and Russia, other GCC countries and developing countries like India and China. These studies provide adequate background to perform our own barrier identification and analysis for UAE.

## 1.2 Research objectives

In the previous section, it is indicated that there exists a knowledge gap between formulating a strategy for green hydrogen development without studying the barriers affecting it. Another gap highlighted is understanding of the interrelationships the barriers have among themselves. Therefore, in this research, a new approach is proposed to address these both gaps. The objective of this thesis is to contribute to the literature on green hydrogen development in UAE, by identifying the relevant barriers for the case of UAE and research the most influential barriers. Additionally, the interrelationships between the identified barriers are researched. The proposed methodology is to identify the barriers, establish the interrelationships between them and rank the influence of these barriers on the development to green hydrogen in UAE. This methodology is supported by conducting interviews with experts in this field. These identified factors are then analysed by the Decision-making trial and evaluation technique (DEMATEL) and then weighted by the Best-Worst Method, both are multi-criteria decision-making (MCDM) methods implemented to provide insights into the relationships and influence of barriers. These methods are explained in detail in section 2.4. This research will result in identification of barriers to green hydrogen development in UAE, the interrelationships between the barriers and the ranking of their influence on the development. Furthermore, the combination of DEMATEL and BWM has not been implemented to analysing barriers to green hydrogen development and can, therefore, provide new insights in the matter.

## 1.3 Research question

For achieving the objectives of this research, the following research questions should be answered:

***Q.1 "What are the barriers for large-scale development of Green hydrogen technology in UAE?"***

***Q.2 "What are the most influential barriers to the development and what interrelationships exists between them?"***

To answer the main research questions, the following sub-research questions should be answered:

1. What are the barriers to the development of green hydrogen in UAE?
2. What are the most influential barriers to the development?
3. How are the barriers interrelated?

## 1.4 Scope

The scope of this research is defined by the following categories:

- **Country**: The country of emphasis is United Arab Emirates, and the barriers are studied from the perspective of the country's policies and technical landscape.
- **Technology**: Hydrogen is produced by a variety of processes, however, only fully decarbonized hydrogen (green hydrogen) produced by water electrolysis is considered in the thesis. Therefore, partially decarbonized (blue hydrogen) and fossil-based hydrogen (coal and methane based) are not considered in the analysis.

## 1.5 Research approach and data collection

In problem definition it is highlighted that a lot of attention is directed towards the potential of green hydrogen in UAE but there has been no published strategy to achieve that potential. The potential barriers to development have not been identified previously. Additionally, studying the interrelationships that exist between these barriers and ranking the barriers by their influence on the development can aid the policymakers in formulating a strategy for green hydrogen development. To answer the first main research question, initially, barriers are identified through literature study. These barriers are then discussed with experts in this field by scheduling interviews. The interviews also provide valuable insights from a practical perspective and helps in identifying more barriers. In addition to the interviews, questionnaires are implemented to obtain values required to use the discussed methodology. The questionnaire is divided into three parts. The first part is used to obtain the values for DEMATEL. The second part of questionnaire is used to obtain values for BWM, and the third part gives the respondents the option to add any barriers they think have been missed out. Figure 4 provides an illustration of the structure of research approach. More information on the approach used, interview protocol, expert selection, data collection can be found in Chapter 2:.

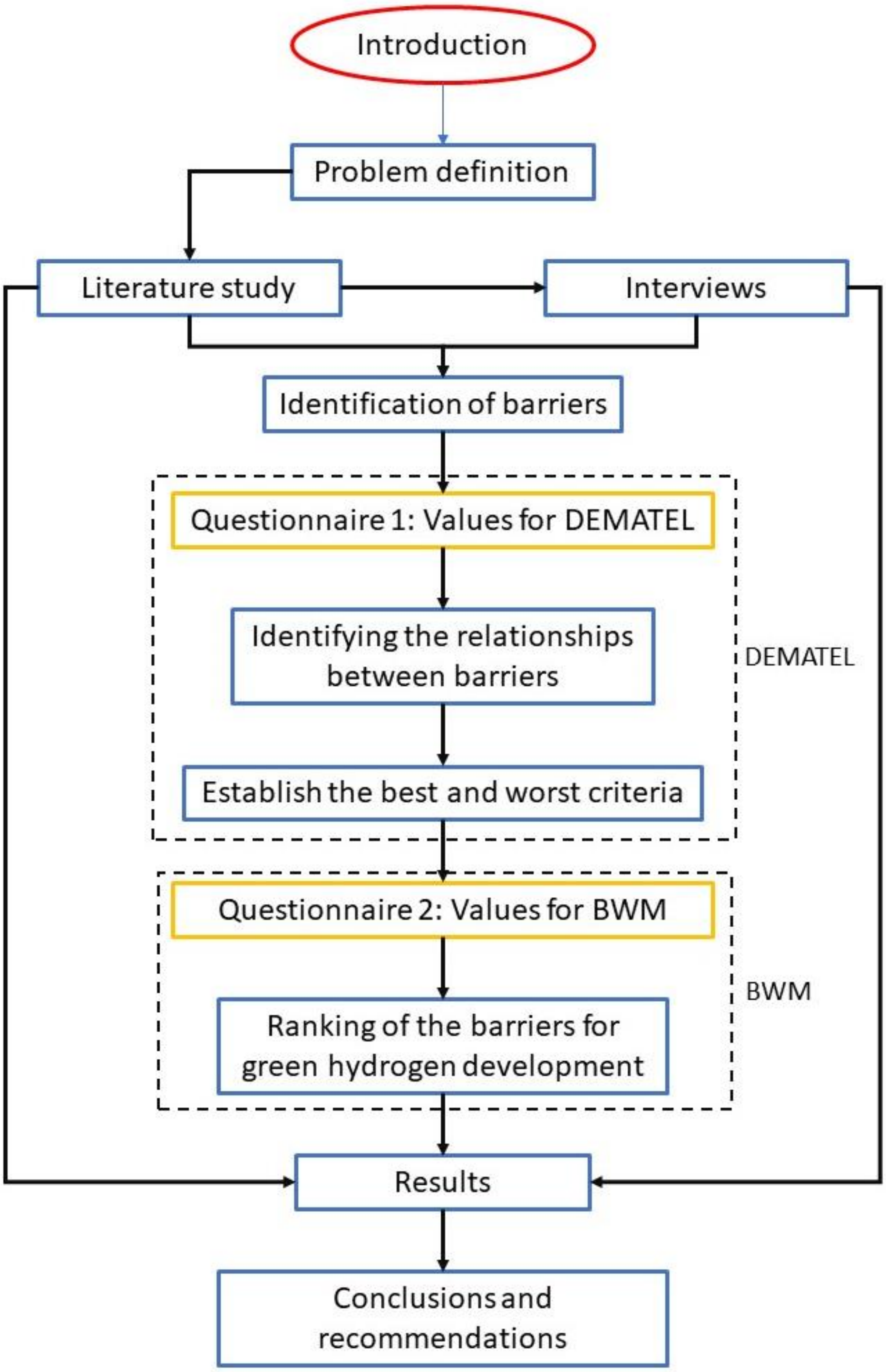


*Figure 4 Research approach*

## 1.6 Relevance

A lack of knowledge about development of green hydrogen production in UAE was indicated as the primary research gap. The literature study was focussed on formulating a comprehensive set of barriers for development of green hydrogen. The interviews from experts working in field of renewable energy, hydrogen, project developers, academia and citizens validated the literature study. They also explained barriers prevalent in practice. The final set of barriers formed could prove beneficial for policy makers and strategists in making a scientifically informed decision for large-scale development.

The identification of barriers to green hydrogen and analysing them to provide information about influence of the barriers and the interrelationships existing between them is unique to this research. The research also involves extensive literature study and interviews with stakeholders involved in the development of green hydrogen. Another distinctive result from this research is a model of the implemented framework of a combination of DEMATEL and BWM. This model can be repurposed to fit the purpose of barrier analysis for future research.

One of the main outcomes that can be used from this research is that it is crucial to address and acknowledge the barriers related to a process or product from different perspectives, but the inclusion of the analysis of their influence and interrelationships plays an important role in understanding the transition process and thus increasing the chance of success. Therefore, this research could provide a valuable source of knowledge and thus represents a necessary part of groundwork to be undertaken before designing the policies, strategies and socio-technical structure for the development of green hydrogen economy in UAE.

## 1.7 Thesis structure

This section will provide a brief outline of the thesis chapters:

### Chapter 1: Introduction

This chapter introduces the research topic and explains the context in which this thesis is written by highlighting the knowledge gaps in the existing literature. The research objectives are defined based on the knowledge gaps identified. The objectives contribute to formulating the research questions for the thesis. Furthermore, the scope of the thesis is defined. Next a brief explanation is provided on the research methodology and the methods of data collection used and the relevance/contributions of the thesis are highlighted. Finally, the outline of this thesis is provided

### Chapter 2: Research methodology

This chapter explains in detail the steps followed to execute this project. The chapter has been subdivided into different steps explaining the literature search, selection of interviewees, structure of interviews, selection of research methodology and the computation framework implemented to address the research questions

### Chapter 3: Literature review

This chapter investigates the role of green hydrogen in decarbonizing the economy. Followed by that the focus is narrowed to Power-to-Hydrogen supply chain to create a foundation for identifying the barriers

## Chapter 4: Barrier identification

This chapter is divided into two sections identifying relevant barriers from literature and interviews respectively. These barriers are divided into four categories: technical, economic, institutional and social. At the end, a combination of barriers identified is shown.

## Chapter 5: Barrier Analysis

This chapter actually carries out the barrier analysis with a combination of barriers identified, values allocated by experts and the chosen framework of DEMATEL-BWM.

## Chapter 6: Discussion

This chapter points out the key results from the analysis and interpret the data. The limitations of the research are mentioned, and recommendations are provided for future research.

## Chapter 7: Conclusion

This chapter brings the thesis together by answering the research questions explicitly.

# Chapter 2: Research Methodology

Examining the research questions, the research can be divided into two main elements. The first includes identification of barriers for diffusion of green hydrogen, while the second involves analysing the found barriers to study the interrelationships between them. A variety of possible pathways and visions exist with varied penetration levels for the diffusion of green hydrogen that can be used to assess the barriers involved. Thus, an exploratory research approach has been incorporated in this study (Sekaran & Bougie, 2016). Exploratory research would help in understanding the basics of the technology and investigates the technical, social, institutional and economic issues that are defined in the research.

The research has been structured into four parts to highlight the relationship between theory and practice to generate a framework and its application: Identification, Investigation, Synthesizing and Computation. This structure of research was formulated to address the knowledge gaps highlighted previously. The first two steps help in answering the first main research question involving the identification and investigation of barriers and the second main question is answered by the next two steps involving compilation of data and computing the influence and relationships implementing the DEMATEL-BWM framework.

The first stage includes gathering information on methods to manufacture, store and transport green hydrogen, and the existing government schemes to promote the use of green hydrogen. This stage would also identify the barriers from the existing literature. The second step involves conducting interviews and surveys to understand the practical aspects and barriers of introducing green hydrogen. The third step is to synthesize the data from step 1 and step 2 by comparing them to formulate a questionnaire to generate relative rankings. The fourth step involves using the data from step 3 and DEMATEL-BWM to formulate the critical barriers and interrelationships between them.

## 2.1 Step 1: Identification of existing information

Initially, the focus of the literature search was to cover different perspectives on the role of hydrogen in decarbonization. The literature from renewable and future energy system, green hydrogen economy and hydrogen production. Scopus was used to identify relevant scientific literature.

The annual reports published by “The International Renewable Energy Agency (IRENA)” and “International Energy Agency (IEA)”; titled “Hydrogen: A renewable energy perspective”, “Renewable Power-to-Hydrogen Innovation Landscape Brief” and “The Future of Hydrogen” respectively, aided the preliminary investigation in understanding the history of hydrogen use, the future potential uses of green hydrogen along with the production processes involved and the socio-economic aspects pertaining to it.

The initial investigation was performed using the keywords of “Power to Hydrogen” OR “Power to X” OR “Green Hydrogen supply chain” separately. The location filter was not activated as the focus was to study the supply chain in different countries and identify the critical factors. The search resulted in 424 articles for which a filter of subject area “Energy” was applied. This resulted in 290 articles. Further, the articles with abstracts providing an overview of supply chain of hydrogen or green hydrogen either from an economic or technical perspective. This was done to understand the supply chain and identify the bottlenecks in it. The social and institutional perspectives are not considered at this stage as both are location specific and would be covered at a later stage. A total of 34 relevant articles were selected. The rest of the articles included were found from references made in the article found from the database and some articles were found on google scholar for understanding specific technologies in further detail.

In stage 2, the Scopus database was referred to identify the barriers in the diffusion of Power-to-Hydrogen and Green Hydrogen. The search terms: “Barriers to Power-to-Hydrogen” OR “ “Barriers to Hydrogen” OR “Barriers to Green Hydrogen” OR “Barriers to hydrogen economy” OR “Challenges to Power-to-Hydrogen” OR “Challenges to Hydrogen” OR “Challenges to Green Hydrogen” OR “Challenges to hydrogen economy” were searched separately. The inclusion criteria for the papers were:

- The publication year should be between 2016 and 2022. This was done to identify barriers only relevant to this time frame (current) which would account for the development in hydrogen technology, the change in regulations and awareness of the technologies.
- The subject area being limited to “Energy”.

In stage 3, the search criterion was narrowed to focus on the middle east countries or oil or natural gas abundant countries aiming for development of hydrogen economy. This was done to include the underlying factors of similar social structure and abundance of fossil fuels and existing network of resources. For this stage, both Scopus and Google Scholar were used to identify more literature related to GCC countries mainly United Arab Emirates. The search terms initially used in Scopus were “Barriers OR Challenges to hydrogen” OR “ ‘Green hydrogen’ AND GCC OR UAE“ but this gave us no results on Scopus. So, in order to capture the institutional and social barriers specific to the country of UAE, relevant literature on the challenges to the development of renewable energy was search on Scopus and Google search using the term “Barriers OR challenges to renewable energy AND GCC OR UAE”.

Apart from the interviews and literature review, the research paper by Saccini et al. (2020) was the most significant in providing a backbone to this thesis. The study provided a complete analysis of the barriers to green hydrogen development in Italy. The study starts with thorough assessment of the literature on the use of green hydrogen, methods for manufacturing, storing and transportation. The research then identifies relevant barriers by thoroughly studying the supply chain for the case of Italy and finally provides recommendations for overcoming the identified barriers. This enabled me to understand and identify the barriers in case of UAE. The research provides a structure for this thesis to build on.

## 2.2 Step 2: Practical investigation through interviews

The transition to green hydrogen is a complex topic and the study of literature solely would not suffice in understanding the topic from all perspectives. Interviews were scheduled to get stakeholders opinions and practical experiences. The semi-structured interview technique was implemented as it enables the development of open-ended questions to guide the discussion with the participants whilst not being constrained by the interviewees' answers to the questions. Divergence from the questions is permitted as it would represent the participants' own thinking which may generate data relevant to the subject that would not have been generated otherwise (Sekaran & Bougie, 2016)

The following steps are followed at this stage:

1. Choice of specialists

This is the starting point for the interview procedure, the choice of specialist is heavily influenced by the research's core topic. The barriers for Power-to-Hydrogen (Green Hydrogen) development are the core focus of the study. Individuals in the best position to offer information from different perspectives are chosen.

| Criteria for selection | Explanation of criteria |
|---|---|
| Related to the research topic | Power-to-Hydrogen, Renewable energy |
| Educational background | Varied backgrounds for diversity |
| Work-experience | Multidisciplinary for highlighting different perspectives |
| Position | Different experience levels for diversity |
| Country | United Arab Emirates |

*Table 2 Expert selection criteria*

The experts were chosen using the criteria in Table 2 and gathered from multiple sources. The experts were selected primarily through personal network and LinkedIn, furthermore the snowballing method was implemented which permits additional experts to be identified through the existing network (Sekaran & Bougie, 2016). After the experts were identified, an invitation to participate was extended via personal e-mail or a personal message on LinkedIn. In terms of sample size, 7 experts were interviewed.

| Stakeholder category | Interviewee reference | Role |
|---|---|---|
| Industry | A | Professional: A company professional focussed on investing in energy projects in UAE. |
| Industry | B | Professional: A company professional working on the production of green hydrogen in GCC countries. |
| Industry | C | Professional: Working in the hydrogen mobility sector in middle east. |
| Industry | D | Professional: Health and safety auditor in UAE |
| Academia | E | Professor: Researcher focussed on the subject of energy transition in middle east. |
| Government | F | Professional: Former member of UAE government body involved in planning energy strategy |
| Society | G | Citizen in UAE and potential end-user of fuel cell vehicle. |

*Table 3 Interviewee list with profiles*

2. Preparation and planning

To conduct the expert interviews, an extensive literature review was undertaken to be well-versed in the subject and have a clear understanding of the topic being examined. The interview questionnaire is an important component for the interviews and was formulated with the following objectives:

- Green Hydrogen's potential uses and major developments.
- The government's policies to promote the development of green hydrogen.
- Identification of pilot projects for green hydrogen and understanding the social acceptance for it
- The challenges for introducing, producing and using green hydrogen in the energy mix.
- Actions to be undertaken to overcome the barriers.

These objectives were specifically chosen to address the element of practical investigation in the research methodology. The topics cover the aspects of understanding of green hydrogen usage, the pilot projects undertaken, role of the government in promotion of hydrogen, barriers from the perspective of the interviewee and the actions to be undertaken to overcome the challenges. The gained knowledge was implemented in formulating semi-structured interviews for identification of barriers from perspectives of experts.

3. Conducting interviews

The following interview protocol was implemented

| Phase | Things to remember | Content |
|---|---|---|
| Introduction and disclaimer | Introducing the interviewee to the context of the research and his/her rights regarding the same | The interviewee is provided with an introduction to the aim of the study, the approximate duration of the interview and his/her rights related to recording, data use and anonymity. |
| Interviewee introduction | To get to know the background of the interviewee | Could you give us a short introduction of yourself, including your role in the organization and your educational background |
| General questions | To gain information on P2H development and the potential production of green hydrogen | We are here today to discuss the production of green hydrogen and its use. Could you please explain what your current understanding is about the potential of green hydrogen in UAE? |
| | | How beneficial could be the production of green hydrogen on the energy mix? |
| | To gain information on the P2H supply chain starting from production, storage, transportation, and distribution. Check for any mention of problems associated with the technology or process | What is your opinion on the current technologies/processes available to incorporate green hydrogen in the energy mix? |

| | | |
|---|---|---|
| | To gain information on the current and upcoming government schemes and projects.<br>Ask more about a specific project he/she is directly associated with. | What are the efforts in terms of schemes or pilots being undertaken by the government to promote the use and production of green hydrogen? |
| Questions related to barriers | Before discussing the barriers, explain the methodology of DEMATEL-BWM so that he/she could aid in the quantitative analysis alongside<br><br>Informing the interviewee, the different categorization of barriers implemented in the study and if he/she could describe the barriers in categories.<br><br>In the event the interviewee forgets to discuss a relevant barrier identified through the literature, politely prompt him/her to say something about it. | What is the most common category of barriers you know of/ your organization faces when you think of/tried introducing green hydrogen production? |
| | | Discuss specific/relevant barriers categories to the interviewee in detail. |
| | | Discuss examples that the interviewee can provide to illustrate the barrier better. |
| | | For the barriers discussed, what value would you assign on the scale of influence? |
| | | For each barrier discussed, what actions should you or your organization implement to overcome the barriers? |
| Concluding remarks | Try to know their opinion about an approximate timeline for the transition to happen. | Could you shed some light on the potential of green hydrogen to replace conventional energy sources in the future? |

| | | |
|---|---|---|
| | Informing the interviewee about the data usage policy, ask for permission to use the data and if he/she would approve the use of specific comments for the thesis. | Closing remarks in the future of green hydrogen in the country and informing the post-interview details. |

*Table 4 Interview framework*

| |
|---|
| Importance of adding renewable energy to the energy mix |
| Role of green hydrogen as the fuel of future |
| Green hydrogen value chains and processes |
| Barriers to the development of Power-to-Hydrogen |
| Discussion on the DEMATEL-BWM methodology |
| Role of stakeholders in terms of the hydrogen economy |
| Future of “Green Hydrogen Economy” in the country |

*Table 5 Interview themes*

4. Data analysis and interpretation

In this step, for each of the interviews in the step 3, minutes were made and sent to the interviewees for approval and consent to use excerpts in the research. The minutes are segregated according to the themes highlighted in Table 5 to analyse the comments by the interviewees. Additionally, it is imperative to analyse the relative rankings provided by the interviewees for the set of barriers.

## 2.3 Step 3: Synthesize data and creation of questionnaire

A comparison was performed between the barriers acquired from step 1 (theory) and step 2 (practice). The comparison of theory with practice aids in creating a summary of both perspectives’ findings. This summary is then used to formulate a questionnaire to generate relative rankings for the identified barriers through both steps. The respondents are identified from LinkedIn and personal network and the demographic for the respondents can be found in Appendix C. A total of 22 responses were recorded. The values gained through this questionnaire is used as an input for both DEMATEL and BWM frameworks to generate the cause-effect groups and influence of barriers respectively. The paper by (Sadehnezhad, Zaranejad, & Gheitani, 2014) presents a guideline for formulation of a questionnaire for this study.

The questionnaire for collecting data consists of three parts:

- First section: Pair-wise comparison of the dimensions with each other (interactions of barriers with each other). The values are assigned between 0 – 4 with 0 being no influence and 4 being very strong influence. These values are used to formulate the DEMATEL framework.

- Second section: Pair-wise comparisons of the barriers to the impact on development of green hydrogen. The values are assigned between 1 – 9 with 1 being equal importance and 9 being absolutely more important. These values are used to formulate the best and worst vectors in BWM method
- Third section: Addition of comments to explain the values assigned, to mention any missing barriers and actions to be undertaken to overcome them in their opinion.

The design of the questions required the respondents to respond in the specified scale. A total of 22 experts on the topics of renewable energy, hydrogen and business development with varied backgrounds, roles and experience in the supply chain were identified and contacted to respond to the questionnaire.

Apart from the interviews and questionnaire, some individuals were contacted through personal network and LinkedIn to answer questions on specific subject matters.

## 2.4 Step 4: Computation using DEMATEL-BWM method

The aim at this stage is to compute all the data into the following methodology to identify the critical barriers to the development of green hydrogen and highlight the interrelationships between them. This step provides the core results for the main research question 2. This step started with a literature study to formulate a methodology best suited for the objectives.

The Scopus database was used to look for methods to study barriers to energy transition. The search initially was focussed to identify the prevalent methods used for barrier analysis, so the search criteria used was “Barrier Analysis”; this yielded 525 results. Further, a filter of keyword “barrier analysis” was implemented reducing the results to 71. To be included for further study, the abstracts of these 71 were studied to filter results involving a study of renewable energy transition or renewable technology diffusion. This resulted in studying 13 articles of which 10 articles implemented some type of multi-criteria decision-making (MCDM) methods. This resulted in further study of MCDM methods to figure out the best methods for the research.

Multi-criteria decision-making (MCDM) methods are a group of methods developed to evaluate available alternatives and identify the best option when multiple factors influence the objective (Agyekum, 2021; Mostafaeipour, 2021). For the nature of our study on barrier analysis we focussed on methods of pairwise comparison to understand the inter-relationships between the barriers. There are a few other methods that have previously been used for similar multi-variable relationship decision-making studies. The most used methodologies for tackling sustainable energy decision making problems are Analytical Network Process (ANP), Analytical Hierarchy Process (AHP), Weighted sum, Interpretive Structural Methodology (ISM) and Elimination et choice translating reality (ELECTRE) (Wang, 2009). Table 6 shows different methodologies implemented for similar studies with their advantages and disadvantages.

| Method | Advantages | Disadvantages |
|---|---|---|
| **ANP** | Considers dependent and independent criteria | Inability to evaluate a single element for its strengths and weaknesses. |
| **ISM** | Highlights differences between elements and criteria they are based on | Inability to consider more criterions and is not statistically validated |
| **ELECTRE** | Categorizes interactions into mutual strength, mutual weakness and antagonistic | Inadequate to represent large number of interactions |
| **DEMATEL** | Determines direct and indirect relationships between criteria | The integration of direct/indirect relation is unclear |
| **AHP** | Improved usability due to a reasonable system comparing all criteria with each other | Complexity increases several manifolds with every criterion added as the number of comparisons is n! (factorial) |
| **BWM** | Determines relative importance of criteria by comparisons between best, worst and the rest. | The input of best and worst criteria is subjective. |

*Table 6 MCDM methods overview (Mandic, 2015; Pamučar, Ecer, Cirovic, & Arlasheedi, 2020; Rezaur Rahman, Chowdhury, Firoze, & Rahman, 2019; Tavana, Shaabani, Javier Santos-Arteaga, & Raeesi Vanani, 2020)*

For achieving the objective of this thesis, the chosen methodology should perform two main tasks:

1. Different barriers have different importance in the decision-making process. Identifying high and medium-high impact barriers to the diffusion of the technology can aid to promote it.
2. These barriers should be further explored to understand the interdependencies and classify them into cause-effect groups.

There is not a single MCDM method which alone can fulfil both the objectives; therefore, two separate methods need to be chosen to fulfil the objectives and compatible with each other. MCDM methods generally can be categorized into two categories, one that are focussed on calculating weights for criteria while assuming that the criteria are independent and others that are focussed on modelling the interrelationships between criteria. In Table 6; ISM, AHP and BWM represent the first category while ANP, ELECTRE and DEMATEL represents the latter.

DEMATEL is able to fulfil the objective of highlighting interrelationships better than ANP and ELECTRE in the following ways:

- The calculation procedure of ELECTRE is more complex as compared to DEMATEL and the final result provides dominance of one criterion over other and not a cause-effect relationship like DEMATEL (Vakilipour, Sadeghi-Niaraki, Ghodousi, & Choi, 2021).
- The main difference between DEMATEL and ANP is that ANP presents relationships between criteria with respect to each other at the moment of the goal having the best result. On the other hand, DEMATEL presents the relationships in cause-effect groups independent of the end-goal (Ortíz, Felizzola, & Isaza, 2015).

BWM is the chosen methodology to address the influence of barriers over AHP and ISM for the following reasons:

- AHP establishes the influence of criteria by comparing all criteria with all. This results the computation dependent on number of criteria (n!). BWM reduces these comparisons to two vectors 'Best-to-others' and 'Others-to-worst'. For this study, 18 barriers are identified which would have led to $6.4 \times 10^{15}$ values to be determined for AHP but only 34 for BWM (Rezaei, 2015).
- ISM has the disadvantage of unable to address the influence the criteria have on the system, BWM builds up on this advantage and is able to address the importance of criteria and influence on the system (Dhawale, 2019).

A methodology is proposed based on the combination of Decision-making trial and evaluation laboratory (DEMATEL) and the Best Worst Method (BWM). This combination has significant advantages over individual methods and aid in covering up each other's weaknesses whilst making it more reliable. BWM helps to prioritise and rank barriers based on the best (most impactful) and worst (least impactful) barrier, while DEMATEL aids in examining and mapping causal relationships between barriers (Mangla et al., 2021). This section would further explain the classic methodologies of DEMATEL and BWM and the proposed combination of both.

## Decision-making trial and evaluation laboratory (DEMATEL)

Decision-making trial and evaluation technique (DEMATEL) was first developed by the Geneva Research Centre of the Battelle Memorial Institute to visualize the structure of complex relationships through matrices or digraphs (Liu, Lo, & Liou, 2020). DEMATEL aids the development of map to display inter-relationships between the factors considered. This map converts the interdependency relationships into cause-effect groups and finds the critical factors of a complex system through an impact relation diagram which useful to analyse and solve complex and intertwined problems (Si, You, Liu, & Zhang, 2018).

DEMATEL has previously been used to analyse interrelationships, key factors, and measure criteria weights across different fields of science from medicine to energy studies. This ability to analyse the interdependent relationships amongst barriers and rank them for long-term strategic decision making for the transition makes DEMATEL technique fit for our purpose. One of the limitations for this methods is, the aggregation of expert judgement does not incorporate the relative weight assigned (Si et al., 2018). However, this limitation is circumvented by implementing BWM explained later in this section.

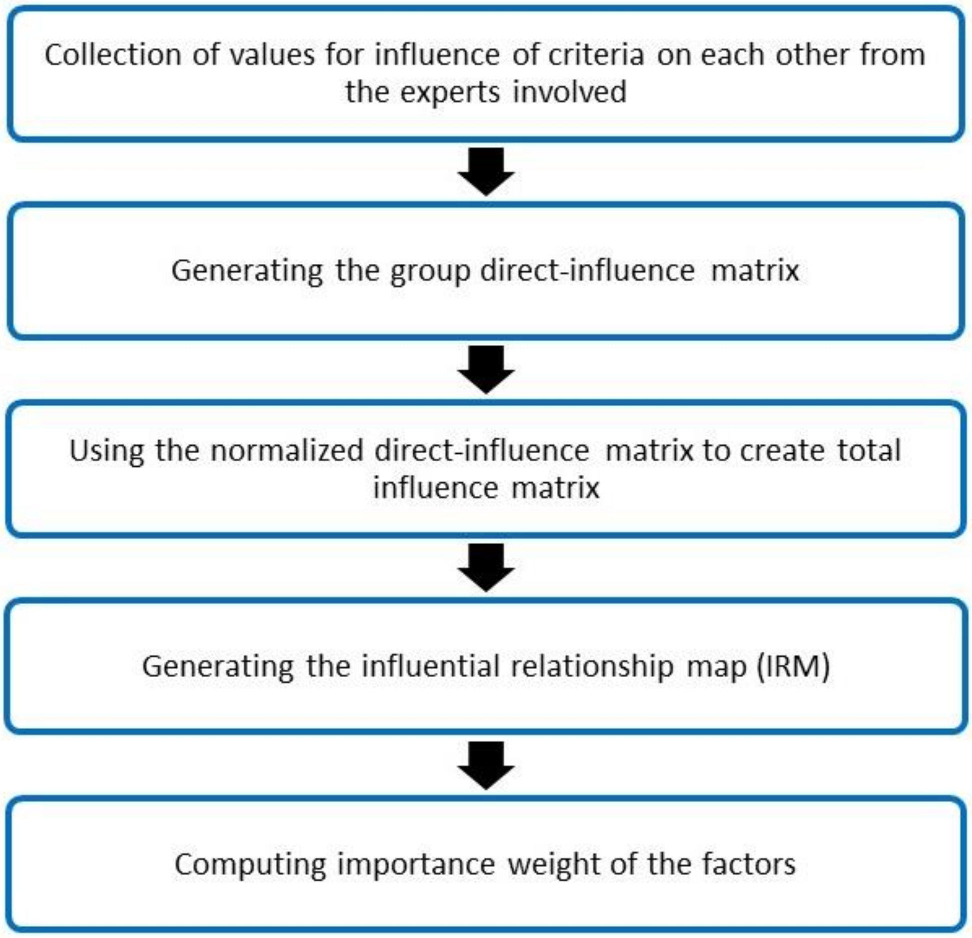


*Figure 5 Process for classic DEMATEL method (Yazdi, Khan, Abbassi, & Rusli, 2020)*

The DEMATEL technique originally has four steps as illustrated in Figure 5, but for this study it has been expanded into seven steps for the ease of understanding and combining with BWM. The steps have also been modified for the purpose of this study using Si et al.'s methodology as reference. The steps involved in DEMATEL technique are as follows:

1. **Identification of factors/variables from literature**

Factors/Variables in our case are the barriers to development of green hydrogen. These variables need to be determined through studying relevant literature.

2. **Assigning scores to each barrier**

The dimensions for the evaluation scale for impact assessment are defined to represent different degrees of influence the barriers have on each other. These are divided as follows, "no impact (0)", "Low impact (1)", "Medium impact (2)", "High impact (3)", "Very High impact (4)." This scale of scores can be changed according to the requirement of the study.

3. **Construction of individual and group direct-influence matrix**

The relationships between 'n' number of barriers B=$\{B_1, B_2, \ldots, B_n\}$ are assigned scores based on the influence of barrier $B_i$ has on barrier $B_j$ and would be evaluated by experts in a decision group G=$\{G_1, G_2, \ldots, G_l\}$ where 'l' is the number of experts. The mean score amongst the respondents is used to form the individual direct-influence matrix 'M' provided by the $kth$ expert where all the principal diagonal elements are equal to zero

$$M_k = [m_{ij}^k]_{n \times n}$$

where $m_{ij}^k$ represents the evaluation of decision maker $G_k$ on the degree of influence. Therefore, by aggregating for l experts' opinions the group direct-influence matrix M can be obtained

$$M = m_{ij} = \frac{1}{l} \sum_{k=1}^{l} m_{ij}^k, \qquad i, j = 1, 2, \ldots, n.$$

These calculations result in compiling the values assigned by 22 experts for the influence of one element on another into a single matrix. Each element of the matrix denotes the direct relationship that exist between the criteria in consideration. The next step deals with normalizing this data in a common scale between 0 to 1 for replicability and comparison of data in future studies.

4. **Establish the normalized direct-influence matrix**

From the direct-relation matrix M calculated by equation 1, a normalized direct-relation matrix $D = \left[d_{ij}\right]_{n \times n}$ is obtained by

$$D = c \times M$$

where,

$$c = \min\left\{\frac{1}{\max_i \sum_{j=1}^{n} m_{ij}}, \frac{1}{\max_j \sum_{i=1}^{n} m_{ij}}\right\}, \qquad i, j = 1, 2, \dots, n$$

The direct-relation matrix M is normalized so that all the values assigned are in range between 0 and 1. This converts the data into a common scale which can be replicated regardless of the initial score range used (in this case from 0 to 4 as highlighted in step 2 for this section). This resulting normalized direct relation matrix indicates only the direct relationships between elements. To account for both, direct and indirect effects, we must calculate the total influence matrix *T*.

5. **Calculation of the total influence matrix**

Using the normalized direct-influence matrix $D$, the total influence matrix $T = \left[t_{ij}\right]_{n\times n}$ is computed by summing up both direct and indirect effects by

$$T = D + D^2 + D^3 + \cdots + D^h = D(I - D)^{-1}$$

Where $I$ is Identity matrix and when $\lim_{h\to\infty} D^h = [0]_{n\times n}$

The indirect effects is the cascading effect one element would have on another but is caused by a third element. This is represented by $(I - D)^{-1}$ in the total influence matrix equation. The elements of the resulting matrix denote the total influence one barrier has on another. For a particular element, the corresponding row denotes the influence the element has over other elements and the corresponding column denotes the effect other elements have on it.

6. **Calculating the sum of the rows and columns of the total influence matrix**

In the total relation matrix T, the value of every individual element in rows represents the amount of influence the element has on others and the column values represent the effect other elements have on it. For calculating the prominence and net cause-and-effect values, let the sum of rows and columns of the total-influence matrix $T$ be denoted by the vectors $R$ and C, respectively:

$$R = [r_i]_{n\times 1} = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1}, \qquad i, j = 1, 2, \dots, n$$

$$C = \left[c_j\right]_{1\times n} = \left[\sum_{i=1}^{n} t_{ij}\right]_{1\times n}, \qquad i, j = 1, 2, \dots, n$$

In these equations, $r_i$ denotes the sum of $i$th row of the matrix $T$ which represent causal influence and $c_j$ denotes the sum of $j$th column of the matrix $T$ which represents the effect influence. After calculating the values for the vectors $R$ and $C$, we add individual elements of the vectors to give us the values for "prominence" representing the degree of influence of the $i$th variable and subtract the individual elements of the vectors to give us values for the "net cause-and-effect" of the $i$th variable.

The value of "prominence" is the summation of both the effect of the barrier on others and of the others on barrier. This means the value represents the total amount of interactions the element has with others regardless of the direction of influence. The "net cause-and-effect" represents the difference in the value of influence (row) and value of affect (column). The net difference between these values determine the cause-and-effect groups.

7. **Create the Influential Relation Map (IRM)**

An Influential relationship map is created by mapping the dataset of $(R_i + \mathrm{C}_i, \mathrm{R}_i - \mathrm{C}_i)$ in which $(R_i + \mathrm{C}_i)$ is the horizontal axis vector denoting the degree of central role the said factor (barrier in this case) plays in the system and $(\mathrm{R}_i - \mathrm{C}_i)$ is the vertical axis vector denoting the net effect of the factor on the system. In simple terms, $(R_i + \mathrm{C}_i)$ is the "Prominence" vector and $(\mathrm{R}_i - \mathrm{C}_i)$ is the "Relation" vector. From Figure 6 we can visually understand the complex casual relationships among the barriers for valuable insights. The quadrants represent the category of the barrier it will classify into based on its value on the scale of prominence and relation. A simple description of these quadrants can be given as follows:

- **Quadrant 1**: Shows core factors or intertwined givers (cause barriers with high importance)
- **Quadrant 2**: Shows driving factors or autonomous givers (cause barriers with low importance)
- **Quadrant 3**: Shows independent factors or autonomous receivers (effect barriers with low importance)
- **Quadrant 4**: Shows Impact factors or intertwined receivers (effect barriers with high importance)

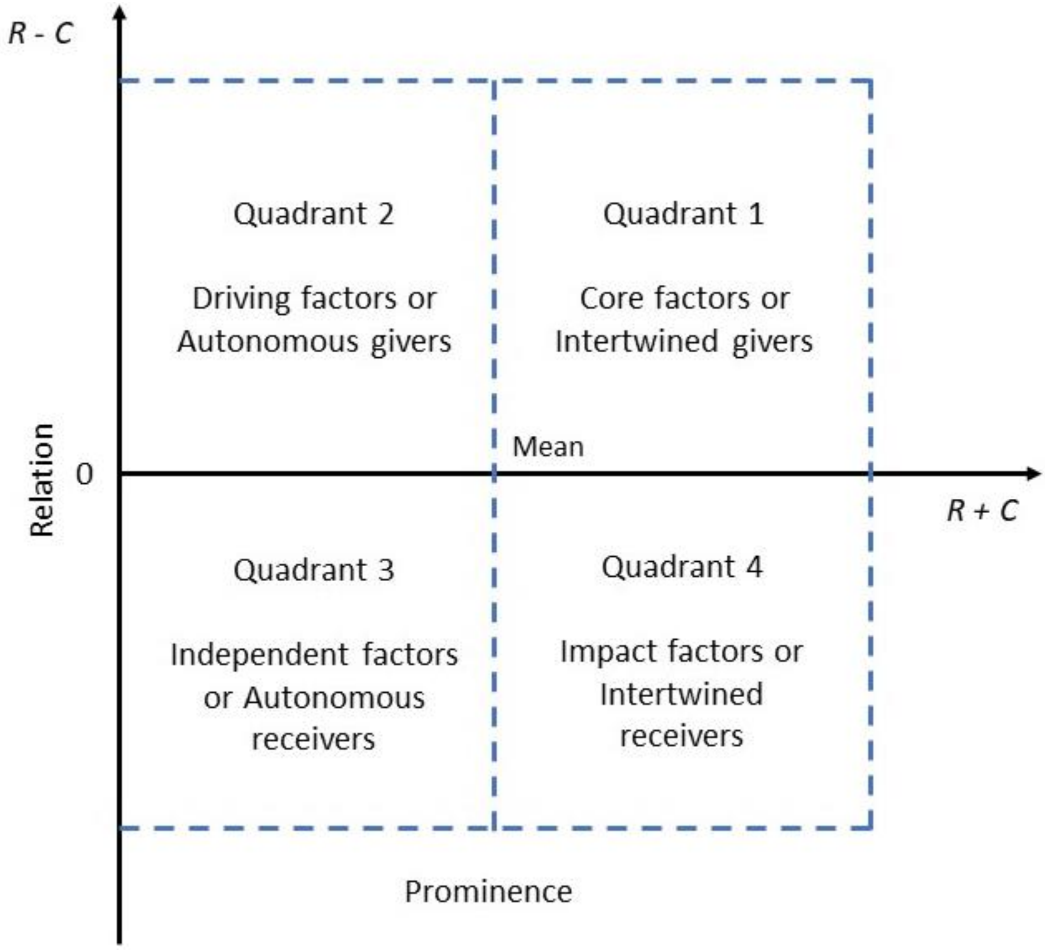


*Figure 6 Four-Quadrant IRM*

8. **Threshold value for creating the relationship map**

After the IRM is constructed from the matrix T, sometimes the IRM could be too complex to show valuable information. A threshold value θ is therefore determined to filter out the negligible effects. It is implemented such that any element of matrix T having a value higher than the determined θ is selected and converted into a relationship on IRM. If the threshold value is too low, many factors would be included making IRM too complex to comprehend, inversely, a higher value would result in eliminating some important factors. The value of threshold is usually determined by experts through discussions, results if literature review or the average of all elements in the matrix T (Si et al., 2018).

## Best-Worst Method (BWM)

The Best-Worst Method is an innovative methodology developed by Rezaei in 2015 that is used to evaluate the weights of a set of decision criteria (Rezaei, 2015). This method was developed to build on the shortcomings of traditional Analytic Hierarchy Process (AHP) methods mainly by reducing the number of pairwise comparison thus reducing the data inconsistencies. BWM even though being a comparatively recent methodology has previously been used to solve real-life problems in energy, supply chain management, manufacturing, transportation, education, investment and healthcare (Pamučar et al., 2020).

The abilities to be easily combined with other MCDM methods and to quantify the influence of each factor with higher consistency makes this method perfect for the objective of this thesis. The limitations of this method are: (1) With the increase in the number of criteria the problem complexity increases several manifolds. (2) BWM ranks factors with respect to the best and worst criteria but fails to address the interrelationships between the other factors (Mostafaeipour, 2021). This study aims to overcome these limitations by using DEMATEL in combination with it.

- DEMATEL is used prior to implementing BWM to identify the best and worst criteria from its relationship map. Identifying these criteria reduces the amount of pairwise comparisons to be undertaken to rank the order of influence of barriers.
- DEMATEL also helps to address the interrelationships between barriers.

This methodology is explained further in the sections below

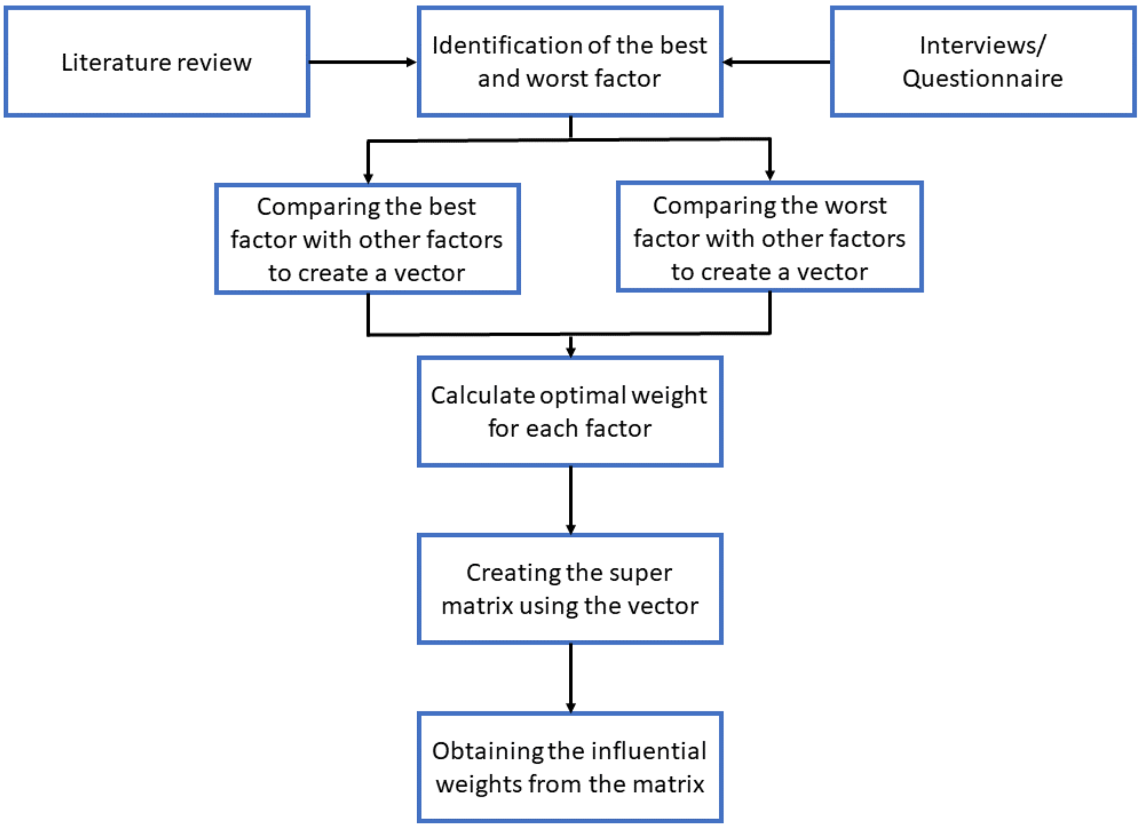


*Figure 7 Process for Best-Worst Method*

Figure 7 illustrates the process of implementing BWM and obtaining the criteria weights. The steps involved in BWM are as follows and been modified for this specific thesis (Liu et al., 2020; Mostafaeipour, 2021; Rezaei, 2015):

1. **Formulating a set of decision criteria**

The decision criteria (in our case barriers to diffusion) are usually determined through literature analysis and interviews with relevant actors. These criteria are expressed as $(b_1, b_2, \ldots, b_n)$ which are relevant to reach a decision.

2. **Determine the best and worst criteria**

From the barriers identified in the step 1, the expert opinions are used to identify the best (most impactful) and worst (least impactful) criteria. This is a critical step for further analysis and hence results. However, in this research, the best and worst criteria are determined from the relationship map obtained from DEMATEL method.

3. **Use the Best and Worst criterion to compare with the other criteria to formulate BO (Best-to-others) and WO (Worst-to-others) vectors respectively**

The BO vector is formulated by comparing the best criterion $B$ over the criterion $i$. The resulting vector is represented as

$$A_B = (a_{B1}, a_{B2}, \ldots, a_{Bn})$$

Where $a_{Bj}$ indicates the comparison of best criterion $B$ over criterion $j$ and $a_{BB} = 1$.

Similarly, the WO vector is shown by

$$A_W = (a_{1W}, a_{2W}, \ldots, a_{nW})^T$$

Where $a_{jW}$ indicates the comparison of criterion $j$ over Worst criterion $W$ and $a_{WW} = 1$.

The values assigned in this step are on a scale of 1 to 9 and denote the following: 1 – Equally important, 2 – Somewhat between equal and moderately important, 3 – Moderately more important, 4 – Somewhat between moderate and strong, 5 – Strongly more important, 6 – Somewhat between strong and very strong, 7 – Very strongly important than, 8 – Somewhat between very strong and absolutely more important, 9 – Absolutely more important.

4. **Calculating the influential weights for all criteria $(\boldsymbol{w_1^*}, \boldsymbol{w_2^*}, \ldots, \boldsymbol{w_n^*})$**

The optimal criteria weights are calculated based on Linear Programming (LP) Model. The weights are calculated for each pair of $w_B/w_j$ and $w_j/w_W$, we have $w_B/w_j = a_{Bj}$ and $w_j/w_W = a_{jW}$.

To satisfy the conditions for all $j$, a solution exists where the maximum absolute difference should be minimized

$$\min \max_j \left\{ \left| \frac{w_B}{w_j} - a_{Bj} \right| , \left| \frac{w_j}{w_W} - a_{jW} \right| \right\}$$

Subjected to

$$\sum_j w_j = 1, \qquad where\ w_j \geq 0, for\ all\ j$$

The above equation can then be modified into a linear objective function for calculation. The linear problem is then formulated as

$$min\ \xi$$

Subjected to

$$\left|\frac{w_B}{w_j} - a_{Bj}\right| \leq \xi;$$

$$\left|\frac{w_j}{w_W} - a_{jW}\right| \leq \xi;$$

$$\sum_j w_j = 1;$$

$$w_j \geq 0, \qquad for\ all\ j$$

Solving this linear problem, the optimal weights $(w_1^*, w_2^*, \ldots, w_n^*)$ and minimized target value $(\xi^*)$ are obtained. $\xi^*$ is an indicator of the consistency of the comparisons. Values of $\xi^*$ closer to zero show a high level of consistency of pairwise comparisons provided by the decision-makers (Rezaei, 2015).

This linear problem is aimed at finding the solution with the lowest value for consistency ratio which satisfies the conditions of:

- Sum of all influential weights should be 1
- The value of influential weights should be greater than 0

### 2.4.1 Combination of DEMATEL-BWM

One of the important outcomes of this thesis is the implementation of a combination of BWM and DEMATEL methods for the analysis of barriers. This section would focus on the implementation of the methodology alongside the merits for choosing it. An illustration of the proposed methodology is displayed in Figure 8.

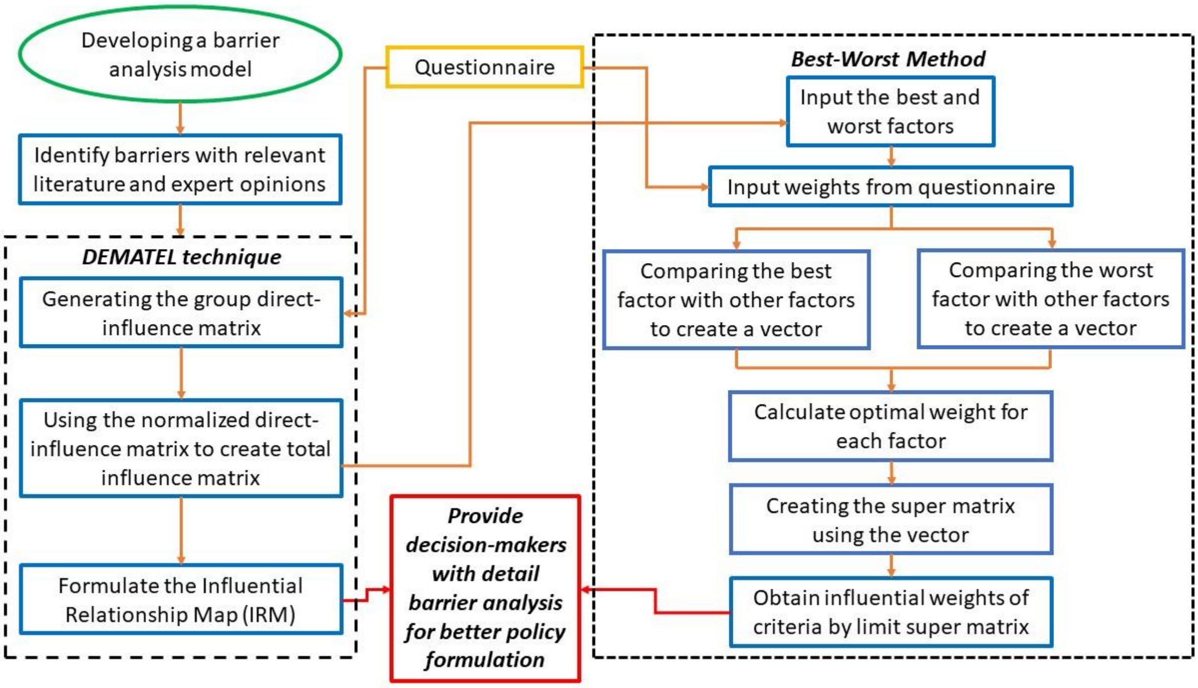


*Figure 8 Research methodology: Combination of DEMATEL-BWM*

The combination builds on shortcomings of both methods and gives us the following advantages (1) Creation of Influential Relationship Map (IRM) that gives a visual representation of interdependencies between the barriers. (2) The BWM shores up the shortcoming of DEMATEL by calculating the weights for all barriers thus providing the order of influence they exert. (3) DEMATEL enhances BWM by addressing other relationships between other criteria and not just the best and worst one's. The results from the proposed methodology would provide a clear picture of the barriers and the interactions between them which would be crucial in tackling them.

# Chapter 3: Literature Review

This section starts with providing information on the role of hydrogen in de-carbonization. It further narrows the focus on the P2H technology, and the processes involved. The processes concerning production, storage, transportation, and utilization. This is followed by discussing the hydrogen landscape in both countries to identify the stakeholders, the government projects, policies and regulations associated with the hydrogen value chain. This section answers the research sub-question ***"What are the barriers to development of green hydrogen in UAE?"***

## 3.1 Current hydrogen uses and future projections

According to International Energy Agency (IEA), 120 million tonnes of hydrogen are produced which is about 4% of global final energy, of which 95% is generated from natural gas and coal. The remainder 5% is generated as a by-product from chlorine production through electrolysis (Gielen, Taibi, & Miranda, 2019). As a result, no significant hydrogen production utilizes renewable energy.

Oil refining sector currently leads the hydrogen usage chart for which UAE is in no shortage of. The production costs for hydrogen vary regionally with factors including the prices of electricity, fossil fuels and carbon. Currently, the middle east region (mainly UAE) offers the cheapest method of production by natural gas without CCUS with a cost of USD 1/kg$H_2$ (IEA, 2019).

## 3.2 Intermittency in a renewable electricity network grid

Most sustainable energy sources, especially solar and wind, are intermittent in nature, giving rise to scenarios where energy demand is high and supply is low, and vice versa. This causes challenges for grid operation, requiring the need for balancing the system and energy storage technologies. Different types of electric storage technologies exist like large electric batteries, pumped hydroelectric storage, compressed air energy storage and Power to Gas (P2G) solution. This technology is unique as it stores power in chemical energy storage rather than storing in batteries. Power to Hydrogen (P2H) is the configuration with the highest technology Readiness Level (TRL), making it more reliable and effective solution (Saccani, Pellegrini, & Guzzini, 2020).

Production of hydrogen by using renewable energy especially when there is a surplus of generation in the system can help in avoiding curtailment and hence improving the return on investment for the RES asset owners. In this case, the hydrogen is produced by electrolysis, which is the process of splitting water into hydrogen and oxygen by passing electricity through it. Thus, hydrogen can be stored like conventional fuels and used to generate clean energy like RES Technologies. Implementation of P2H technology can benefit the power sector in the following ways (IRENA, 2019b; Purohit, 2022):

- Reduction of variable renewable energy curtailment.
- Provision of long-term energy storage.
- Providing grid balancing services
- Power can be transported or traded over long distances as hydrogen.

## 3.3 Power to Hydrogen

With the declining costs of renewable energy sources like solar and wind, their use for production of green hydrogen is growing.

Figure 9 Illustration of Power to Hydrogen (P2H) concept shows the Power to Hydrogen concept and the uses for the green hydrogen produced by water electrolysis.

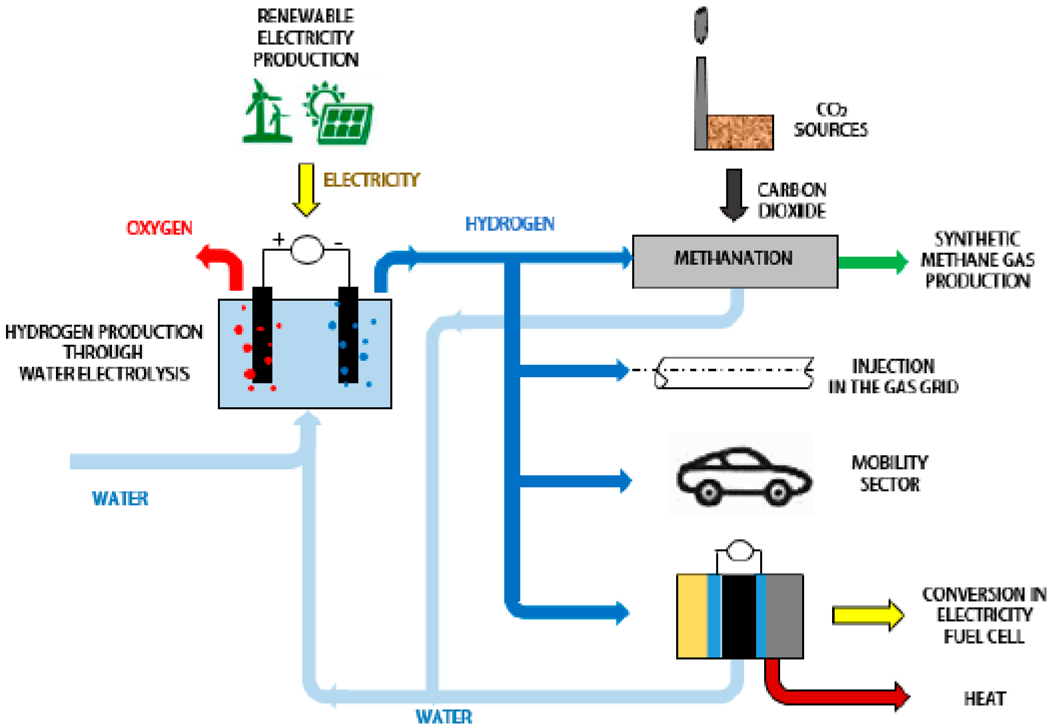


*Figure 9 Illustration of Power to Hydrogen (P2H) concept (Saccani et al., 2020)*

As shown, green hydrogen produced can be used for multiple purposes across different sectors (Saccani et al., 2020).

- It can be used as a raw material in industrial processes.
- It can be used as a fuel in the transport sector.
- It can be converted to Synthetic Natural Gas (SNG), i.e., Power to Methane (P2M).
- It can also be converted back into electricity and heat by using fuel cells.

Green Hydrogen offers long term flexibility due to its ability to storage high amount of energy. Development of storage, distribution and transmission infrastructure is critical to bring out green hydrogen's full potential. The Power to Hydrogen supply chain is divided into four stages for better understanding: Production of hydrogen, Storage of hydrogen, Transportation and Utilization.

### 3.3.1 Hydrogen production

Currently, the grey hydrogen generated by steam reforming dominates the UAE market which has low $CO_2$ emissions. There is a need to shift to green hydrogen which has zero $CO_2$ emissions. Hydrogen can be produced from fossil fuels, biomass and even water as shown in Figure 10. Natural gas is responsible for 75% of the global hydrogen production, followed by coal and biomass respectively (Sinha, 2021). This research will focus on the production of green hydrogen through water electrolysis. About 0.1% of green hydrogen is produced by this method as of now (IEA, 2019).

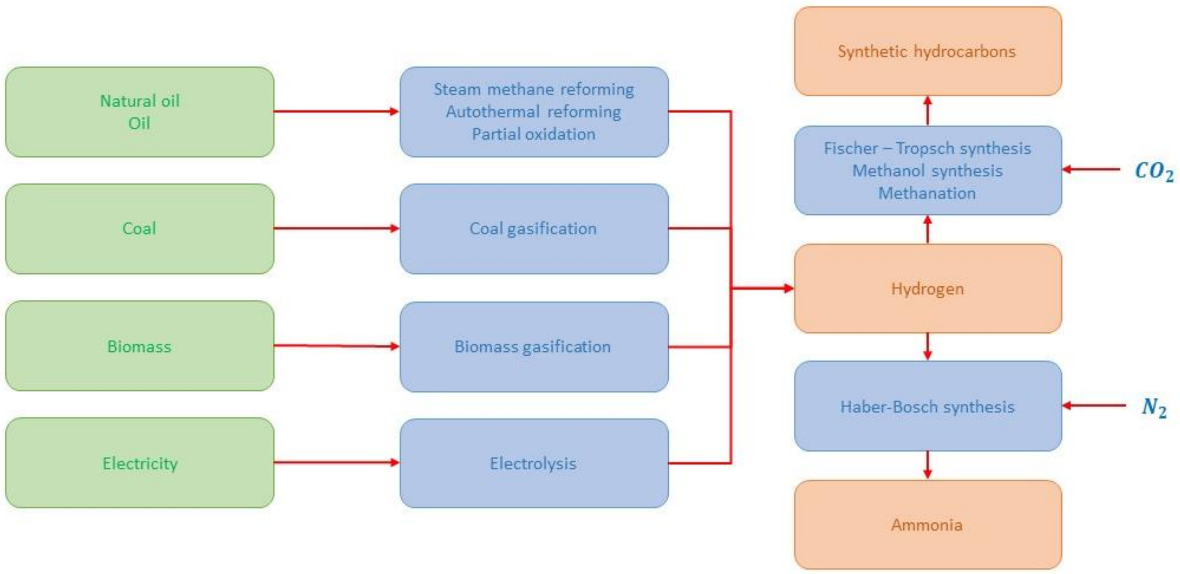


*Figure 10 Hydrogen production methods (Cell & Undertaking, 2017)*

To produce green hydrogen through water electrolysis, electricity generated from renewable energy sources is used. Electrolysis implemented by using an electrochemical device called electrolyser, where the power supply splits the water into hydrogen and oxygen. These ions $OH^-$ and $H^+$ are collected at separate electrodes by crossing a liquid or solid membrane electrolyte. The membrane installed to prevent oxygen and hydrogen gases from mixing by keeping them apart. The system is continuously fed purified water using a pump for smooth functioning. A Polymer Electrolyte Membrane (PEM) Electrolyser is generally used because of its reliability, commercial availability, low cost of operation, moderate cost of investment and moderate efficiency (Purohit, 2022).

### 3.3.2 Transportation

The preferred option for transporting hydrogen depends on the application while the state of hydrogen determines the cost effectiveness. Hydrogen can be stored and transported in pure form or as an intermediate energy carrier (Netherlands Enterprise Agency, 2020).

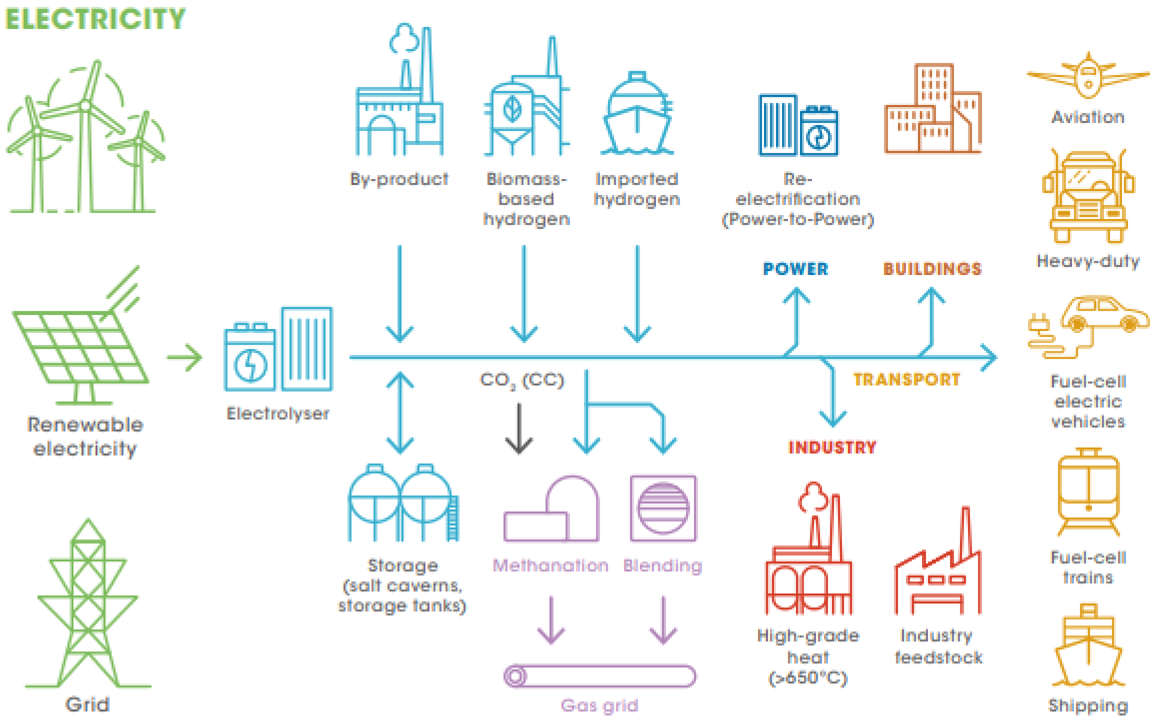


*Figure 11 Hydrogen storage and transport pathways (IRENA, 2019b)*

Gaseous tube trailers are used when the quantity of hydrogen demand is small (<1MT/day) and is unpredictable. Liquid tankers are used to transport liquid hydrogen and can store up to 5 times more hydrogen per load than gaseous tube trailers and used when the demand is regular but not large enough for pipelines. These methods of transportation are suitable for short distances by road or rail. The large and stable (15+ years) demand of hydrogen requires use of pipelines and compressors for transportation (Berger, 2021). It is also possible to convert natural gas infrastructure. Once these lines are established, the cost competitiveness would increase and opens further extensions of network to cover short to long distances over land. Currently a new method is being research which combines hydrogen with a chemical carrier for easier conversion for end-use and for transporting over long distances by shipping.

Transportation of hydrogen is one of the main cost components in the value chain. The cost for transportation and storage of liquid hydrogen (LH) are high due to the higher energy losses from liquefication and the shipping involved. The costs for compressed gaseous hydrogen and ammonia are similar but the components vary. For ammonia, synthesis and reforming are the main component, whereas hydrogen pipelines and storage tanks are the main components in CGH value chain (Netherlands Enterprise Agency, 2020).

### 3.3.3 Storage

The hydrogen produced through water electrolysis is in a gaseous state, which has a low energy density per volume making it unsuitable for commercial energy generation. To obtain a high energy density, it must be stored under pressure to maintain a concentrated state. Figure 12 shows a simple hydrogen storage system.

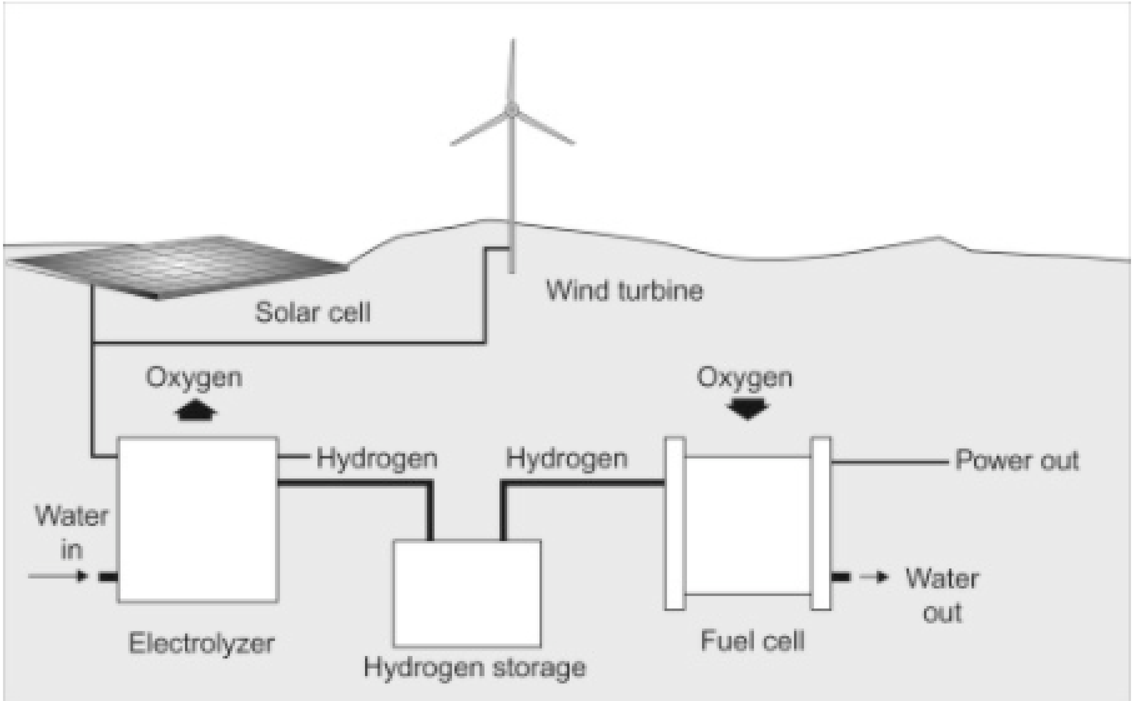


*Figure 12 Hydrogen energy storage system (Breeze, 2018)*

Composite or steel tanks store hydrogen under pressures of 350-700 bars to provide a low-volume storage for general power generation applications. However, larger volume storage units are essential to support the hydrogen economy. Underground storage is an alternative that provides very high-volume storage capacity. Underground storage caverns created from salt domes are used to store natural gas and hydrogen has been stored in similar structure by some companies. However this would depend on suitable underground geological features being available (Breeze, 2018).

In terms of underground storage, UAE houses several evaporite deposits mainly, the Hormuz salt of Eocambrian age and Miocene salt (Netherlands Enterprise Agency, 2020). Additionally, the Jebel Dhanna structure near Ruwais Industrial hub and hydrocarbon port, is covered by salt deposits, hundreds of metres thick. These storage sites can be excellent buffer for hydrogen storage which can make the green hydrogen value chain less expensive for UAE (Friedmann, 2021).

### 3.3.4 Utilization

After the storage, hydrogen can be converted in different ways depending on the end-use. It can be used the same way as natural gas, combustion engines to use it as fuel or adapting combustion engines to generate hydrogen for power. However, hydrogen fuel cells are projected to be the most important method of power generation from hydrogen. Several of them already exist and offer an efficiency up to 60% but more complex fuel cell system could offer 70% or 75% efficiency (Breeze, 2018).

# Chapter 4: Barrier Identification

This section reports the different barriers identified through Literature and Interviews, which partially answers research sub-question 1 . Further a questionnaire is used to gain values from experts for the different barriers. All the data is then combined to apply the DEMATEL-BWM framework for analysing the barriers.

## 4.1 Results from literature

After studying the supply chain, a thorough literature study is performed, and the barriers were classified into four main dimensions according to the following:

1. **Technical barriers**: Barriers that are related to a specific component or a system which limits the efficiency, effectiveness, reliability, or safety of green hydrogen technology.
2. **Economic barriers**: Barriers that affect the market penetration of green hydrogen by negatively impacting the economic sustainability.
3. **Institutional barriers**: Barriers that result from a non-conducive legislative framework or a complete lack of it, which hampers the realization of green hydrogen projects.
4. **Social barriers**: Barriers that impact the acceptance of green hydrogen applications by end-users due to lack of awareness or familiarity.

### 4.1.1 Technical barriers

After studying the hydrogen supply chain, the chain is divided into different systems or processes to analyse the barriers to their large-scale development. Following are the technical barriers identified through literature:

#### Low share of electricity generated from renewable energy in the mix

One of the main requirements for producing green hydrogen is excess availability of electricity generated by renewable energy. Currently as can be in Table 1 the share of renewables is very low in the energy mix. Development of renewables is hence an important barrier and has several underlying factors affecting it something that could have its own research question but is not the scope of this project.

#### Low efficiency of electrolysis

Several experts have stated that one of the main technological barrier is the comparatively lower efficiency of water electrolysis compared to alternative production technologies (Chi & Yu, 2018; Ju, Badwal, & Giddey, 2018; Kumar & Himabindu, 2019; Nguyen, Abdin, Holm, & Mérida, 2019; Rashid, Al Mesfer, Naseem, & Danish, 2015). A low hydrogen energy density is required for high compression work which reduces the total cycle efficiency and thus increases the operational costs (Ahmed et al., 2021). This increases the load on its storage, transport and mobility applications. The efficiency of Power-to-Hydrogen is compared to other technologies in Table 7.

| Technologies | Efficiency |
|---|---|
| P2H (only hydrogen production) | 60 – 70% |
| Methane steam reforming | 70 – 85% |
| P2H (conversion to electricity) | 33 – 42% |
| Electric battery | 60 – 88% |
| Compressed-air energy storage | 70 – 90% |

*Table 7 Comparison of technology efficiencies (Saccani et al., 2020)*

## Renewable source of fresh water

One of the main requirements for P2H supply chain is availability of freshwater sources. Current water electrolysis technology does not include any measures for filtering the salt in seawater and deionizing it to be fit for use. Nine litres of purified water is required to produce 1 kg of green hydrogen (Cochrane, 2021). Therefore to achieve significant green hydrogen production capacity, adoption of large desalination infrastructure or the technological maturity of direct seawater and other saltwater electrolysis systems would be required (Griffiths, Sovacool, Kim, Bazilian, & Uratani, 2021).

## Shortage of hydrogen storage infrastructure

Currently, there is no enabling regulatory framework concerning hydrogen projects in the UAE or Saudi Arabia. The most technologically mature and currently viable options include, naturally occurring geological formations like salt caverns, engineered geologic sites like depleted oil and gas reservoirs, dedicated vessels and facilities like compressed or liquid storage tanks and battery storage (Griffiths et al., 2021). Table 8 provides a comparison of storage options and costs associated with different hydrogen states and intermediates.

| | Gaseous | | | | Liquid | |
|---|---|---|---|---|---|---|
| | **Salt caverns** | **Depleted gas fields** | **Rock caverns** | **Pressurized containers** | **Liquid hydrogen** | **Ammonia** |
| **Capacity** | 300–10,000 t $H_2$ per cavern | 300–100,000 t $H_2$ per field | 300–2,500 t $H_2$ per cavern | 5-1,100 kg $H_2$ per container | 0.2-200 t $H_2$ | 1-10,000 t $H_2$ per tank |
| **Time frame** | Weeks to months | Months (seasonal) | Weeks to months | Daily | Days to weeks | Weeks to months |
| **Current LCOS (€/kg)** | 0.2 | 1.67 | 0.62 | 0.16 | 4.03 | 2.48 |
| **Forecast LCOS (€/kg)** | 0.09 | 0.94 | 0.2 | 0.15 | 0.83 | 0.76 |
| **Geographical availability** | Limited | Limited | Limited | Not limited | Not limited | Not limited |

*Table 8 Hydrogen storage technologies (Griffiths et al., 2021)*

At the moment, the focus for green hydrogen storage is on batteries. The battery storage also doubles up as an option of grid stability. A few projects have been implemented for battery storage but none of them are specifically aimed at storing electricity generated by hydrogen. On the other hand, underground storage facilities are a valid option but are limited in availability with 3 known sites in UAE (Netherlands Enterprise Agency, 2020).

Compliance with safety and security regulations also has an impact on the technological and economic viability of the storage technology and can thus act as a barrier to specific storage types like batteries and hydrogen-state storage. Hydrogen gas detectors are required to secure indoor storage spaces (Eljack & Kazi, 2021).

## Safety issues of hydrogen

Hydrogen is a highly flammable gas with a wide flammability range in air (4-75% by volume) and a requirement to be stored at a high-pressure range (10,000-15,000 psi) to produce sufficient mass for a practical application (Dawood, Anda, & Shafiullah, 2020; Schmidtchen, 2009). These physical and chemical properties require dedicated measures to be taken to prevent hydrogen leaked risks. This in combination with the safety limitations and countermeasures of labour laws result in complex designs of P2H production and storage plants (Saccani et al., 2020; The United Arab Emirates Goverment, 2009).

Hydrogen is able to attack and damage iron and steel used to build storage containers, pipes, valves and other equipment at point of leakage. This can lead to propagation of cracks in the pipework, usually an issue with direct injection of hydrogen into the natural gas network. This destructive ability is referred to as hydrogen embrittlement (Eljack & Kazi, 2021). Several studies demonstrate that low-concentration hydrogen injections (10-15% by volume) or higher (15-20% by volume) into the natural gas distribution network pose no risks (Melaina, Antonia, & Penev, 2013; Quarton & Samsatli, 2018; Saccani et al., 2020; Sinha, 2021). This injection is done to reduce $CO_2$ emissions from natural gas. Transmission grids have higher pressure compared to the distribution grid and thus made of high strength steel. This additional pressure increases the effects of hydrogen embrittlement, so the concentration levels are lower than the distribution grids. In order for transporting hydrogen over larger distances via pipeline, a purpose-built network is necessary (Ogden, 2018).

### Blending with natural gas

Injection of hydrogen into the existing natural gas network is an important step towards a sustainable energy mix. The concept is to serve as a transportation and distribution system to feed green hydrogen into the current gas network. This is done by using relatively low concentration of hydrogen, less than 5-15% by volume, without risking end-user place (Saccani et al., 2020). Due to the difference in chemical properties, on a volumetric level, hydrogen has a substantially lower energy density than natural gas. As a result, the end-users of this mixture of gas would require a greater volume than users of pure natural gas to achieve the same energy generation due to the reduction in average calorific content. For example, blending 10% hydrogen by volume would only replace 3.2% of natural gas demand (Mulder, Perey, & Moraga, 2019; Sinha, 2021). These variations in fuel quantities transferred can result in complications when calculating energy usage bills and would require additional equipment to facilitate this calculation.

### Maintenance and repair network availability

A significant and long-term investment is required for a large-scale electrolysis system which is accompanied by maintainence costs. After the commisioning of the project, lower operational costs and availability of support are major difficulties faced. To ensure this, establishing a service organization or a network of department experts and local technicians is critical; with the goal being to avoid unplanned shutdowns during the system's lifetime. Measures such as inspection programs, intergrated monitoring systems, preventive maintainence and availability of spare parts are required (Saccani et al., 2020).

### Lack of skilled personnel and training institutions

The development of the hydrogen economy will create a large demand for qualified workforce both for addressing the needs of the emerging sector and for its smooth functioning. New skills and competencies are required to design and operate green hydrogen plants (Saccani et al., 2020). This workforce would be predominantly originating from two sources; experienced workforce from ONGC sector willing to re-skill to serve in the hydrogen economy and new talented graduates from the universities in UAE (Berger, 2021).

Despite the potential in terms of occupational sector growth, only three of the 79 institutes in UAE offer higher education and training courses with a focus of renewable energy (Alyahya, 2016; Statista, 2019b). More educational programs related to science and engineering need to include hydrogen focus for aspiring students and sector-specific trainings for re-skilling the experienced workforce. The coordination between stakeholders is key to develop these programs and certifications according to the industry standards.

### 4.1.2 Economic barriers

The primary economic barriers according to the literature are:

- High initial investments (CAPEX)
- High operational costs (OPEX)
- High expenses on storage, transportation and distribution

The CAPEX and OPEX for a hydrogen generation system using PEM electrolyser should be calculated to understand the deterrents to investment. For this the system is divided into different cost components according to the system description in Section 3.3 Power to Hydrogen. However, there are several other sub-systems that contribute to the cost. Alongside the usual components of electrolyser, power conversion system, water and gas purification; other components like piping, structure housing and monitoring equipment makes up the electrolyser's balance of plant. Similarly, the hydrogen storage system utilizes a compressor (Sinha, 2021). Following are the major cost components of the P2H system:

- Desalination cost
- Electrolyser cost
- Storage costs
- Compressor cost
- Pipeline cost
- Gas-grid injection cost
- Miscellaneous cost

#### Desalination costs

The industries are inclined to use PEM technology due to its compact design and high system efficiency which produces ultrapure hydrogen. Due to this PEM has seen a drastic reduction in cost and is expected to be the dominant technology for green hydrogen. The PEM run on pure water as an electrolyte solution (Khan et al., 2021). Currently, the leading desalination technology is reverse osmosis (RO) which uses allocation of pressure on a semi-permeable membrane to reject ions present in the water (Beswick, Oliveira, & Yan, 2021).

KSA and UAE are largest producers of desalinated water in the world with 17% and 14% of the global production respectively. The cost of developing, constructing and operating a desalination facility depends on the location of the plant, technology implemented, cost of electrical power, storage, distribution costs and type of raw water. To determine the costs of desalination, Fujairah F1 Extension SWRO, a desalination facility in UAE is considered. This facility operates on the reverse osmosis technology (RO) and the unit production cost was determined to be <0.53 €/$m^3$ – day (Advisian, 2022).

## Electrolyser cost

For a water electrolysis system with PEM electrolyser, shows a comparison of CAPEX and OPEX with respect to the other prevalent method of steam methane reforming with carbon capture, utilization and storage. Table 9 shows the CAPEX and OPEX for two hydrogen production processes. OPEX is calculated using the following assumptions:

- Average electricity purchase cost for industries in UAE: AED 30/kWh (DEWA, 2021) which converts to EUR 72/MWh.
- The currency conversion used for this and subsequent calculations: 1 AED = 0.24 EUR (XE, 2021).
- P2H efficiency: 60-70% (Saccani et al., 2020)
- Fixed Operative and Maintenance (O&M) costs: conservatively assumed to be equal to 4% for both P2H and steam reforming. (Saccani et al., 2020)

| Technologies | CAPEX (€/kW) | OPEX (€/MWh) | Hydrogen production cost (€/kg) |
|---|---|---|---|
| **P2H** | 750 – 1200 | 108 – 122 | 3.6 – 9.2 |
| **Steam methane reforming with carbon capture and utilization (CCUS)** | 575 – 625 | 35 – 41 | 1.3 – 2.5 |

*Table 9 CAPEX and OPEX for different Hydrogen production processes (Saccani et al., 2020)*

## Storage costs

The storage costs change with the state of storage, Table 10 shows a comparison between P2H which stores in hydrogen state and electric battery which would store in electrical energy. Table 10 shows CAPEX and OEPX for different hydrogen storage systems. The OPEX is calculated using following assumptions:

- Average electricity purchase cost for industries in UAE: AED 30/kWh (DEWA, 2021) which converts to EUR 72/MWh.
- P2H efficiency: 60-70% (Saccani et al., 2020)

- Fixed Operative and Maintenance (O&M) costs: conservatively assumed to be equal to 4% for both P2H and steam reforming. (Saccani et al., 2020)
- Battery efficiency: 60-80% (Saccani et al., 2020)
- P2H storage is considered to store hydrogen in salt caverns underground and the LCOS is chosen accordingly (Jülch, 2016).

| | CAPEX (€/kW) | OPEX (€/MWh) | Levelized cost of storage (€/MWh) |
|---|---|---|---|
| **P2H** | 1360 – 4674 | 201 – 245 | 300 - 600 |
| **Electric Battery** | 874 - 4182 | 94 - 180 | 216 – 1080 |

*Table 10 CAPEX and OPEX for hydrogen storage (Saccani et al., 2020)*

## Compressor costs

The hydrogen needs to be compressed before storing in a tank. However, the pressures of both the produced gas and grid are used to determine the compressor for injection into the natural gas grid for transportation and distribution. The compression stage contributes to not only raising the investment but also additional safety and infrastructure requirements (Maestre, Ortiz, & Ortiz, 2021). Table 11 shows the cost parameters for hydrogen compressors.

| Components | Value |
|---|---|
| **CAPEX Hydrogen compressors (€/kW)** | 2100 |
| **Lifetime (years)** | 10 – 12 |
| **OPEX (% of OPEX)** | 1.5 – 4 |

*Table 11 Cost parameters for hydrogen compression (Ferrero, Gamba, Lanzini, & Santarelli, 2016; Saccani et al., 2020)*

## Pipeline costs

The cost of a pipeline is determined not only the distance to be covered but also the pressure requirements, pipe specifications and areas to be traversed (Clerici & Furfari, 2021; Saccani et al., 2020). Table 12 shows the costs involved for constructing new hydrogen pipelines.

| Components | Value |
|---|---|
| **CAPEX $H_2$ pipeline cost (€/km)** | 355,000 |
| **Lifetime (years)** | 60 - 80 |
| **OPEX (% of CAPEX)** | 8 |

*Table 12 Cost parameters for pipeline costs (Kan & Shibata, 2018)*

## Gas-grid injection costs

Hydrogen produced at a production facility can be directly injected into the gas grid for distribution and transmission. Due to the difference in chemical properties, it can only be mixed up to 20% in volume depending on the pressure and the volume of hydrogen injected changes the calorific value of the resulting mixture thus needing more volume than normal gas. The amount of hydrogen injected is determined by admixture limit and location specific grid specifications like pipeline flow, pressure, diameter, producers and end-users (Sinha, 2021). The advantage of injecting hydrogen in the grid is reduction in GHG emissions from end-users and partial hydrogen injection would require limited upgrades to the existing gas infrastructure so the costs would be low. However, for complete utilization of green hydrogen, a complete conversion of gas grids is ideal (Quarton & Samsatli, 2020). Table 13 shows the costs involved for gas grid injection.

| Components | Ranges |
|---|---|
| **CAPEX grid injection station (€)** | 72,250 – 250,000 |
| **Lifetime (years)** | NA |
| **OPEX (% of CAPEX)** | 2 - 5 |

*Table 13 Cost parameters for gas grid injection (Sinha, 2021)*

## Miscellaneous costs

There are additional costs to the general investment for different components. These costs can be categorized as miscellaneous costs and are expressed as a proportion of the overall expenses. These include installation, land preparation, projection planning, design, engineering, control and safety, civil and site expenses.

### 4.1.3 Institutional or Normative barriers

The normative barriers address the challenges faced from a legislative and policy perspective. These contribute significantly to the energy mix and provision of an enabling regulatory market is crucial for hydrogen development. In this section, these institutional barriers would be addressed.

## Lack of legislature for hydrogen

In the case of UAE, there is a complete absence of legislative framework recognizing hydrogen production and storage. Countries that are leaders in decarbonizing their economies have focussed on developing specific tailored strategies for hydrogen. As of May 2021, around 42 countries worldwide have developed their hydrogen strategies (Berger, 2021). Often hydrogen strategies are announced in parallel to the underlying energy system integration strategies, thus providing a framework essential to decarbonizing multiple industries.

Although there is not a clearly defined strategy, there are several individual initiatives oriented towards certain hydrogen objectives:

- **The Energy Strategy 2050**: Launched in 2017, it lays the principal framework for renewable energy and sustainability initiatives including hydrogen in UAE. The goal is for 44% of renewable energy in the final consumption, of which 38% be from natural gas and reduction of carbon footprint of power generation by 70% (The United Arab Emirates, 2021).
- **The UAE/German hydrogen partnership**: UAE and Germany partnered together in 2017 to promote research on transition to renewables and hydrogen economy. the study shows the interest of UAE in energy transition, green hydrogen export, internal consumption of green hydrogen and challenges to achieving it. However, the study has not addressed any policies (Schroder et al., 2021).
- **Partnerships and programs involving the state companies:** Abu Dhabi Hydrogen Alliance is the result of an MoU signed between ADNOC (State oil company of Abu Dhabi), ADQ(collection of Abu Dhabi state-owned entities) and Mubadala (State-owned wealth funded) with a goal of accelerating use of hydrogen (Williams, 2021).

Definition of a particular government body to coordinate and oversee the development of these initiatives and diverse stakeholders would provide a clear roadmap for all stakeholders and pave a clear direction.

#### Lack of incentives, tax breaks and subsidies

The combination of subsidies on fossil fuels and lack of subsidies for renewable energy result in a cascading effect on the development of green hydrogen. At the same time, an absence of cohesive agreement on different subsidies offered only add to the problems (Malik et al., 2019). Although the prices for green hydrogen supply chain have relatively dopped in the past years, it is still not a lucrative investment. Subsidies for at least 30 years are essential to avoid locking into a technology with a long investment cycle (Talebian, Herrera, & Merida, 2021).

### 4.1.4 Social barriers

Public awareness and social acceptance could be considered one of the barriers to the development of P2H technology. The residential and civil population are the end-users of the technology, so the acceptance can affect the business case of certain hydrogen applications like hydrogen mobility. In this section, the societal barriers are addressed.

#### Social acceptance of hydrogen applications

Social acceptance is fundamental for the development of “hydrogen economy” and may be critical in end-user applications. Hydrogen mobility is one such application. A low perceived risk about hydrogen fuel cell mobility should be required for easier diffusion. This can be achieved by defining safety measures and guidelines for end-users and manufacturers. These can be installation of safety equipment in public and private parking spaces. On the other hand, if a revamping of existing infrastructure is required, the economic investment involved could be a deterrent for private users without incentives or subsidies (Saccani et al., 2020). Pilot projects with public transportation services could also be a good start for boosting the adoption of private sector (Michaelowa & Butzengeiger, 2019).

### 4.1.5 Overview of barriers (literature)

An overview of the identified barriers through literature in Section 4.1 Results from literature concerning the development of green hydrogen in UAE is presented below.

| **Technical Barriers** | **Economic Barriers** | **Institutional Barriers** | **Social Barriers** |
|---|---|---|---|
| Low share of electricity generated from renewable energy in the mix | Desalination costs | Lack of legislature for hydrogen | Societal acceptance of hydrogen applications |
| Low efficiency of electrolysers | Electrolyser costs | Lack of incentives, tax breaks and subsidies | |
| Renewable source of freshwater | Storage costs | | |
| Shortage of hydrogen storage infrastructure | Compressor cost | | |
| Safety issues of hydrogen | Pipeline cost | | |
| Blending with natural gas | Gas-grid injections cost | | |
| Maintenance and repair network | Miscellaneous costs | | |
| Lack of skilled personnel and training institutions | | | |

*Table 14 Barriers from literature*

## 4.2 Results from Interviews

This section summarizes the results gained from interviews and explains their significance. The interviews were conducted in a semi-structured format based on the knowledge gained from the literature. Prior to discussing the green hydrogen supply chain, the interviewees were asked to rank the barriers in the order of importance of addressing them. This proved helpful in understanding the interviewees perspective and questions were then oriented accordingly. Table 15 shows the frequency distribution of the barrier ranks by interviewees, the letters correspond to the interviewees listed in Table 3.

| Type of barrier | Rank 1 | Rank 2 | Rank 3 | Rank 4 |
|---|---|---|---|---|
| **Technical** | 1 (B) | 1 (E) | 2 (A,C) | 3 (D,F,G) |
| **Economic** | 4 (A,C,D,E) | 2 (B,G) | 1 (F) | 0 |
| **Institutional** | 1 (F) | 1 (A) | 3 (D,E,G) | 2 (B,C) |
| **Social** | 1 (G) | 3 (C,D,F) | 1 (B) | 2 (A,E) |

*Table 15 Ranking of barriers (frequency-based)*

The opinion between economic and social barriers were divided. Interestingly the interviewees on the upstream of supply chain regarded economic barriers higher while downstream stakeholders regarded the social barriers superior. The institutional barriers were not ranked high. The opinion on technical barriers was neutral as many were confident in the ability for its maturity and improvement over time.

### 4.2.1 Technical barriers

The interviewees identified the following barriers as significant: lack of skilled personnel, low electrolysis efficiency and safety issues of hydrogen. According to the interviewees, low efficiency of electrolysis process resulting in lower cycle efficiency is one of the major barriers to adoption of the technology compared to the technologies available for grey hydrogen currently. Alternatively, it was also emphasized on the similarity with other renewable energy options with respect to the technology maturity curve. Interviewee B explained this barrier by stating:

> *"As an organization focussed on developing and funding hydrogen projects, we usually have to make a choice between investing in carbon capture systems for blue hydrogen or electrolysers for green hydrogen, mainly because cost for blue hydrogen is largely dependent on natural gas which is cheaper in the short term than green hydrogen. With the electrolyser efficiency improving, these situations would not arise."*

The interviewees were confident in the country's ability to exponentially increase the share of renewables in the next 5 years due to the increasing number of projects being undertaken and the favourable partnerships being formed for the promotion of renewable energy. Another aspect interviewees were confident in was the injection of hydrogen in the gas pipelines for either exporting to neighbouring countries or using hydrogen - natural gas mixture for desalination in the short term. Some limitations of desalination process with regards to the proximity of plant to the production facility, outdated technology of desalination plants and increasing demand for freshwater. A researcher in membrane technology shared insights on the existing infrastructure and changing landscape for desalination:

> *"Most of the plants currently in operation operate on natural gas and hence increasing the internal consumption of the resource. The government recognizes the shift towards green technology and are now promoting research in the field of membranes. Several projects are being undertaken to replace natural gas with solar PV and commitments are being made for implementing reverse osmosis technology in at least 50% of the desalination facilities."*

Another important technical barrier indicated by interviewees was lack of skilled personnel. Interviewee G illustrated this by providing an example:

> *"The number of graduates in relevant studies is low. This leads to outsourcing talent from other countries, this would involve relocation, not something everyone is willing to do especially individuals with families and ends up costing more money for an organization."*

On the other hand, complex systems need to be incorporated for smooth functioning of the supply chain which requires a robust repair and maintenance network in place to avoid any unplanned outages. As an emerging technology, the supply chain is subjected to gaps in safety regulations, technical and quality standards. Interviewee D stated the following with regards to the lack of standardizations for the supply chain:

> *"The lack of standardization of safety regulation in the value chain leads to confusion, safety hazards and sometimes loss of revenue. China currently leads the market in standardization of regulations, but these are not recognized worldwide. The global organization, International Organization for Standardization (ISO) and Europe's International Electrotechnical Commission (IEC) are not fully developed to be widely used. UAE recognizes the competitive advantage they hold in creation of safety standards for global consumer hydrogen use, standardizing the process and creating a secure environment for all actors involved."*

### 4.2.2 Economic barriers

Interviewees referred high initial costs (CAPEX) to be one of the most impactful barriers to the development of green hydrogen. The costs components for initial investment identified in the barriers through literature are now referred to as “High CAPEX”. The high cost of electrolyser combined with the uncertainty of technology maturity, proximity from desalination unit and capacity of electrolyser prevents companies from making a large initial investment. “High OPEX” came in a close second as it is factor of CAPEX accounting for 20-30% of CAPEX.

Interviewee A added another essential barrier to the economic cluster. He mentions the inclusion of costs associated with decarbonizing the rest of the supply chain by incorporation of carbon dioxide capture, utilisation and storage (CCUS). He also talks about the partnership signed between Abu Dhabi National Oil Company (ADNOC) and Total for developing and deploying CCUS facilities to capture $CO_2$ equivalent of 5 million tonnes per year by 2030. Developing supporting infrastructure along with green hydrogen production helps making a better case for investment. He elaborates further stating:

> *“UAE has lot of potential for carbon storage and combined with partnerships for research looks like a good investment opportunity. However, that’s not the case, these projects require large investments and bureaucratic support to create a better business case. Additionally, CCUS needs to be implemented extensively for it to be self-sustaining. The supply chain should upgrade simultaneously instead of focusing on a single aspect.”*

The electricity, gas and oil infrastructure are state-owned assets which makes them responsible for upgrading and maintaining the network. When asked about the costs associated with the construction of a new transmission grid for hydrogen, Interviewee F states:

> *“For constructing a new network for hydrogen, we can compare it to the case of electricity lines. In the future with the growth of the hydrogen mobility sector, refuelling stations would be prevalent like battery charging station and require a network of its own. However, electricity is much safer to transport over long distances while hydrogen pipelines would need to exercise strict safety measures for it to be viable. The resulting cost in setting up a hydrogen pipeline network is at least 5 times than that of electricity lines.”*

Interviewee D presented the influence high costs associated with hydrogen have on safety standards, leading to incidents reducing the social acceptance by stating:

> *“Hydrogen storage and transportation comes with different cost associated with it. To maximize profit, often corners are cut in terms of safety, resulting in accidents. Frequent audits and standardized safety protocols need to be established to make sure proper utilization of funds.”*

### 4.2.3 Institutional barriers

One of the main outcomes of interviews is understanding of institutional barriers to development of green hydrogen in UAE. The interviewees provided valuable insights in the functioning of the market and impact of regulatory framework or a strategy. Interviewees indicated lack of framework to be another significant barrier alongside High CAPEX. As of now, UAE does not have defined policies for green hydrogen or a roadmap to achieving it, however, several partnerships and initiatives focused on promotion and research of green hydrogen are in place or being considered. Interviewees were questioned on the influence an absence of regulations has on the business development and points of importance to be highlighted in the framework.

Interviewee E added another barrier to the institutional barriers, she mentions the lack of funding provided for research and development in universities. She states the following regarding it:

> *"Although research is carried out worldwide, promoting localization of this opportunity could be beneficial in terms of improvement of technology, reduction of costs and strengthening public opinion on alternative energy. This reliance on foreign research is very volatile due to its dependence on factors of financial constraints, change in political leaderships or schemes supporting the funding. The hydrogen strategy being developed should aim at internalizing this factor."*

Another barrier added to the list was the limited influence private sector exercises over development of infrastructure and the energy sector collectively. Interviewee C explains this with the example of hydrogen mobility:

> *"Amongst the gulf countries, UAE has the highest number of state-owned companies which makes entering the market very difficult. Hydrogen mobility is an emerging and niche sector and relies heavily on consumer opinion for its successful diffusion. In an ideal scenario, hydrogen powered public transportation would be deployed first in collaboration with the government for demonstration of the technology to the public with minimum infrastructure requirements. However, the state ownership increases the bureaucracy involved and delays the introduction."*

Interviewee F adds to this stating:

> *"The private sector participation is limited due to the loosely implemented legal framework governing their operations. One the reason for not updating the framework is that more than 75% of nationals are currently working in the public sector. However, changes would be implemented soon with the increasing interest from international investors."*

### 4.2.4 Social barriers

Another interesting outcome was understanding the social perspective of the development for green hydrogen. To understand this, general citizens were interviewed, and some stakeholders also added their perspectives to it. One of the most prominent social barriers added through interviews was lack of awareness or understanding of the green hydrogen technology. Interviewee G stated the following regarding lack of awareness and the perspective with its acceptance:

> *"The situation with green hydrogen is similar to that of solar PV. There are subsidies for people willing to install rooftop PV, but the general population is not aware of the benefits associated. There were demonstrations of hydrogen vehicles at the expo last year but unless implemented on a larger scale the effects on general population are limited. The costs of infrastructure modification to the house are also a discouraging element to the adoption."*

Interviewee G also attributed the adoption of hydrogen or alternative energy technology to the reliance on fossil fuels. She explains the following with an example:

> *"In comparison to government and state-owned organizations, households are insignificant when discussing adoption of renewable energy. The electricity prices for households are highly subsidized so that's one reason less to invest in something new. A majority of the expats immigrate to UAE in the dreams of a luxurious lifestyle of flaunting cars but very few have the will to make a move toward sustainability. These practices incline towards more preference to fossil fuels."*

Another researcher in fields of technology diffusion based in UAE stated the following when asked about the importance of social barriers over technical aspects of green hydrogen development:

> *"I think the social aspect is a bigger deal than the technological aspect. Let us look at it this way; considering that there is an abundance of fossil fuels here, should we opt for alternative (and perhaps more sustainable) sources of energy? A shift in the viewpoints from current practices to more sustainable practices would make the answer to the above question a no-brainer. This is how I have come to see this. We are so advanced technologically, that I don't think our problems today are really technical in nature. It's more a question of will."*

## 4.3 Comparison of barriers between literature and interviews

After conducting all the interviews and discussing the barriers identified through the literature the interviewees indicated the relevance of theory in practical applications. The interviewees also highlight some barriers that were not present in the literature and illustrated them with practical examples. Table 16 would present the comparison between barriers found in theory and if they are relevant in practice.

| Category | Barrier | Literature | Interviews |
|---|---|---|---|
| Technical | Low renewable energy penetration | Yes | Yes |
| | Low efficiency of electrolysis | Yes | Yes |
| | Renewable source of freshwater(desalination) | Yes | Yes |
| | Shortage of hydrogen storage infrastructure | Yes | Yes |
| | Safety issues of hydrogen | Yes | Yes |
| | Blending with natural gas | Yes | |
| | Maintenance and repair network | Yes | |
| | Lack of skilled personnel and training institutions | Yes | Yes |
| Economic | High initial investment (CAPEX) | Yes | Yes |
| | High Operational expenses (OPEX) | Yes | Yes |
| | High storage, transmission and distribution costs | Yes | Yes |
| | Additional gas-grid injection costs | Yes | |
| | Costs associated to carbon capture and storage | | Yes |
| Institutional | Lack of legislature for hydrogen | Yes | Yes |
| | Lack of privatization in the energy sector | | Yes |
| | Lack of incentives, tax breaks and subsidies | Yes | Yes |
| | Lack of funding for research | | Yes |
| Social | Social acceptance for hydrogen applications | Yes | Yes |
| | Preference towards conventional fuels | | Yes |
| | Lack of awareness | | Yes |

*Table 16 Comparison of barriers*

There was a clear overlap between theory and practice concerning a majority of technical barriers. The research and interviewees both pointed concerns towards safety of hydrogen, low renewable energy penetration and desalination requirements. The experts also expressed their concerns about the impact of low efficiency of electrolysers has on investment decisions. The lack of locally sourced talent due to lack of courses in renewable energy was also indicated to be a barrier. High initial investment (CAPEX) was identified to be one of the most impactful barriers through both literature and interviews. The theory gives more details into different cost components of production, storage, transportation and distribution. Interviewees suggested an additional economic barrier, costs associated with carbon capture, utilization and storage (CCUS). It could be an important element in the value chain to produce green hydrogen by capturing emissions throughout different sections of the supply chain.

UAE has the case of a complete lack of legislature for hydrogen, to understand the effects of it, the interviews provided valuable information. The interviewees suggested some additional institutional barriers, like lack of funding for research and lack of private sector participation, which could be a probable cause of scarce research in the energy sector and pilot projects showcasing green hydrogen applications. Social acceptance was also inferred to be a significant barrier. The interviewees and theory considered adoption of technology a challenge due to safety issues related to hydrogen and higher cost of adoption compared to the existing fossil fuels. This preference towards fossil fuels was then identified to be a barrier on a larger scale and not just related to consumers. Interviewees also indicated lack of awareness regarding the benefits of the technology to be another important barrier to be considered.

## 4.4 Final list of barriers (literature and interviews)

A total of 20 barriers were identified from literature and interviews combined. To simplify the barrier analysis, separate codes are given for each barrier and category of the barrier. Table 17 presents the final list of barriers along with its explanation. This list of barriers was used to design the questionnaire to collect values for the proposed DEMATEL-BWM analysis and was circulated to the identified 22 experts. This section also answers the first main research question ***"What are the barriers for large-scale development of Green hydrogen technology in UAE?"***

| Dimensions | Code | Criteria | Code | Explanation |
|---|---|---|---|---|
| Technical barriers | $D_1$ | Low renewable energy penetration | T1 | Low chare of electricity generated from renewable sources to produce green hydrogen |
| | | Low efficiency of electrolysis | T2 | Relatively lower efficiency contributes to lower total cycle efficiency |
| | | Renewable source of freshwater (desalination) | T3 | Freshwater is required for electrolysis adding the requirement of desalination |
| | | Shortage of hydrogen storage infrastructure | T4 | Requirement of hydrogen infrastructure to store and have reliable supply |
| | | Safety issues of hydrogen | T5 | Flammability of hydrogen increases risks of accidents and requires complex plant designs and safety limitations |
| | | Blending with natural gas | T6 | Decrease in calorific value of the mixture requires higher volume to be consumed to generate same amount of energy |
| | | Maintenance and repair network | T7 | To avoid unplanned shutdowns, a repair network needs to be readily available |
| | | Lack of skilled personnel and training institutions | T8 | Increase in training courses to address need of increasing hydrogen sector |
| Economic barriers | $D_2$ | High initial investment (CAPEX) | E1 | CAPEX is significantly higher than existing green energy systems |
| | | High Operational expenses (OPEX) | E2 | OPEX is significantly higher than existing green energy systems |

| | | | | |
|---|---|---|---|---|
| | | High storage, transmission, and distribution costs | E3 | Constructing new transmission, distribution and storage pathways require significant investment |
| | | Additional gas-grid injection costs | E4 | The changes required in existing gas-grid equipment to accommodate hydrogen require investment |
| | | Costs associated to carbon capture and storage | E5 | Costs incurred to capture the emissions through the supply chain to produce green hydrogen |
| Institutional or Normative barriers | $D_3$ | Lack of legislature for hydrogen | N1 | Hydrogen production and storage is not recognized as an economic activity and lacks a legislative framework |
| | | Lack of privatization in energy sector | N2 | Energy sector is mostly saturated by state-led investment preventing involvement of private sector |
| | | Lack of incentives, tax breaks and subsidies | N3 | Lack of incentives to encourage P2H and renewable energy market |
| | | Lack of funding for research | N4 | Limited provision of funding to develop technology |
| Social barriers | $D_4$ | Social acceptance of hydrogen applications | S1 | End-users willing to accept new developments in the market like hydrogen cars, built environment, etc. |
| | | Preference towards conventional fuels | S2 | Resistance to accept new technologies due to long-term reliance on fossil fuels and prevalent subsidies |
| | | Lack of awareness in society | S3 | The lack of awareness among general people leads to reluctance to embrace the transition |

*Table 17 Final list of barriers to development of green hydrogen*

# Chapter 5: Barrier Analysis

In this research, barriers to green hydrogen development in UAE have been identified in Chapter 4. Using the methodology explained in Chapter 2.4, this chapter would now conduct the barrier analysis. A model in Excel has been created to carry out the analysis with the values provided by experts in the questionnaire being the input. These values are first used to identify the cause-effect groups which are then used to identify best and worst criteria. These criteria are then used to rank the barriers by their influence.

## 5.1 Determining cause-effect relationships in barrier groups by DEMATEL

Following the steps outlined in the chapter 2 in methodology, we first establish the interrelationships between the different barrier categories namely, technical, economic, institutional, and social. This is done to identify the best and worst barrier groups; this is relevant for two reasons: firstly, the resulting relationships serve as a guideline in determining the threshold value later in the section and secondly, these results are further used as inputs to the BWM to calculate influential weights ahead in this section. This section would now begin stepwise barrier analysis for green hydrogen development.

### 5.1.1 Constructing direct-influence matrix (A)

The interrelationships are shown using the values “0”, “1”, “2”, “3” and “4” which depict “no influence”, “low influence”, “medium influence”, “high influence” and “very high influence” respectively. The initial evaluation matrix is obtained by complying values assigned by 22 experts (refer Appendix C) and then averaging them to formulate the average direct relation matrix (A) shown in Table 18. These values are assigned to illustrate the influence of a group of barriers over others. For example, the influence of technical barriers ($D_1$) over economic barriers ($D_2$) an average value over “3” has been assigned which indicates technical barriers have a “high influence” over the economic barriers. This table was a result of averaging 22 responses from identified experts (refer Appendix A). The codes are derived from Table 17.

| | $D_1$ | $D_2$ | $D_3$ | $D_4$ |
|---|---|---|---|---|
| $D_1$ | 0 | 3.55 | 1.23 | 2.46 |
| $D_2$ | 2.32 | 0 | 2.14 | 2.73 |
| $D_3$ | 2.23 | 3.41 | 0 | 2.77 |
| $D_4$ | 1.27 | 1.59 | 2.55 | 0 |

*Table 18 Average direct-relation matrix ($A_1$)*

### 5.1.2 Calculating the total influence matrix ($T_1$)

From the average direct relation matrix ($A_1$) we normalize the matrix using the maximum value of the sum of rows and columns of the average direct-relation matrix ($A_1$) to obtain normalized direct-relation matrix ($D_1$) shown in Table 19.

| | $D_1$ | $D_2$ | $D_3$ | $D_4$ |
|---|---|---|---|---|
| $D_1$ | 0 | 0.42 | 0.15 | 0.29 |
| $D_2$ | 0.28 | 0 | 0.25 | 0.32 |
| $D_3$ | 0.27 | 0.41 | 0 | 0.33 |
| $D_4$ | 0.15 | 0.19 | 0.3 | 0 |

*Table 19 Normalized direct-relation matrix ($D_1$)*

The direct-influence matrix is normalized to change the scale to between 0 and 1. The normalized matrix only provides us with the direct relationships between the barrier groups so to account for the indirect influences as well the total influence matrix is calculated. The indirect influence is the cascading effect one element would have on another but is caused by a third element. This can be illustrated with the following example, if institutional barriers directly affect economic barriers and economic barriers affect the social barriers; then institutional barriers have an indirect influence on social barriers as well. This influence is represented by $(I - D)^{-1}$.

The total influence matrix is represented by,

$$T = D(I - D)^{-1}$$

where I is a $4 \times 4$ identity matrix and D is the normalized direct-relation matrix. Solving for T we get,

| | $D_1$ | $D_2$ | $D_3$ | $D_4$ |
|---|---|---|---|---|
| $D_1$ | 0.93 | 1.53 | 1.1 | 1.42 |
| $D_2$ | 1.14 | 1.23 | 1.17 | 1.44 |
| $D_3$ | 1.27 | 1.69 | 1.1 | 1.61 |
| $D_4$ | 0.89 | 1.17 | 1.02 | 0.98 |

*Table 20 The total influence matrix ($T_1$)*

From this we calculate "R" and "C" which are sum of rows and columns of the total influence matrix ($T_1$) respectively. The elements in the rows of this matrix represent the influence one barrier group has on the others and the elements in the columns represent the effect other barrier groups have on it. These values would then be used to derive "R+C" defined as the prominence value representing the degree of influence and "R-C" defined as the net cause-effect value where the positive values are the cause variables and negative are the effect variables.

| | $R_i$ | $C_i$ | $R_i + C_i$ | $R_i - C_i$ |
|---|---|---|---|---|
| $D_1$ | 4.97 | 4.23 | 9.2 | 0.74 |
| $D_2$ | 4.98 | 5.61 | 10.6 | -0.63 |
| $D_3$ | 5.67 | 4.39 | 10.07 | 1.28 |
| $D_4$ | 5.45 | 4.06 | 9.5 | -1.4 |

*Table 21 Results of DEMATEL calculation for barrier groups*

### 5.1.3 Formulating the influential relationship map (IRM)

The results from Table 21 are then used to determine the relationship between the four dimensions as plotted in Figure 13

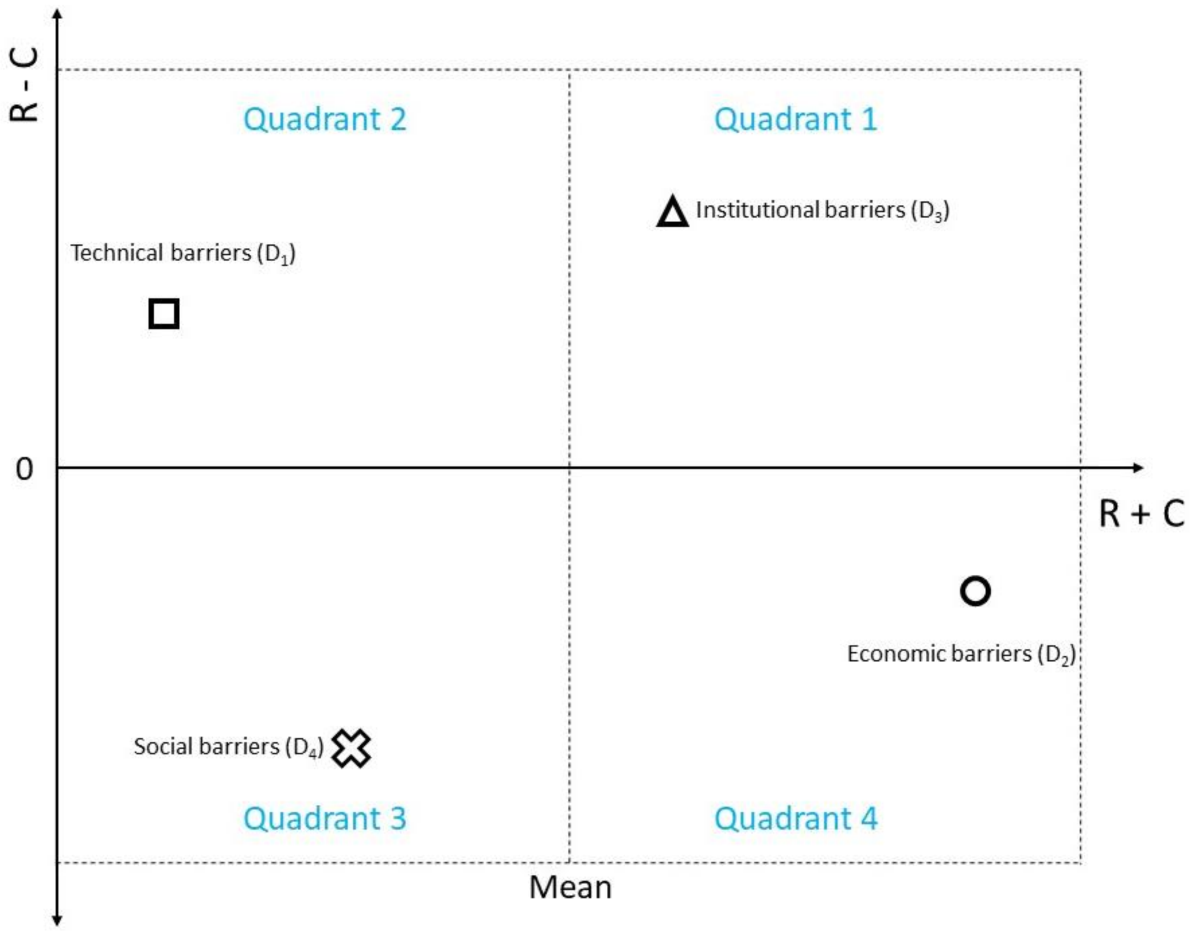


*Figure 13 Barrier group plotting on IRM*

The influential relationship network map is divided into 4 quadrants with each depicting a unique type of relationship

- **Quadrant 1**: Shows core factors or intertwined givers (cause barriers with high importance)
- **Quadrant 2**: Shows driving factors or autonomous givers (cause barriers with low importance)
- **Quadrant 3**: Shows independent factors or autonomous receivers (effect barriers with low importance)
- **Quadrant 4**: Shows Impact factors or intertwined receivers (effect barriers with high importance)

### 5.1.4 Setting threshold value to determine the relationships

To eliminate the negligible relationships between dimensions, a threshold value θ needs to be determined. At first the method of average all the elements of the total influence matrix was used to calculate a threshold value of θ = 1.23. However, this value missed out on some relationships identified through literature and interviews. After analyzing the values in the matrix, a value of θ = 1.1 is chosen. This value is then implemented on the elements of matrix $T_1$ and the determined relationships are illustrated in the Figure 14.

The threshold value is implemented to eliminate the relatively weaker/ less influential relationships between barrier groups. The relationships determined here are used as guideline while calculating threshold value for individual barriers.

### 5.1.5 Establishing the relationships between barrier groups

Using the threshold value, we draw the relationships between barrier groups. The solid lines represent a unidirectional relationship, and a dashed line represents a bi-directional relationship.

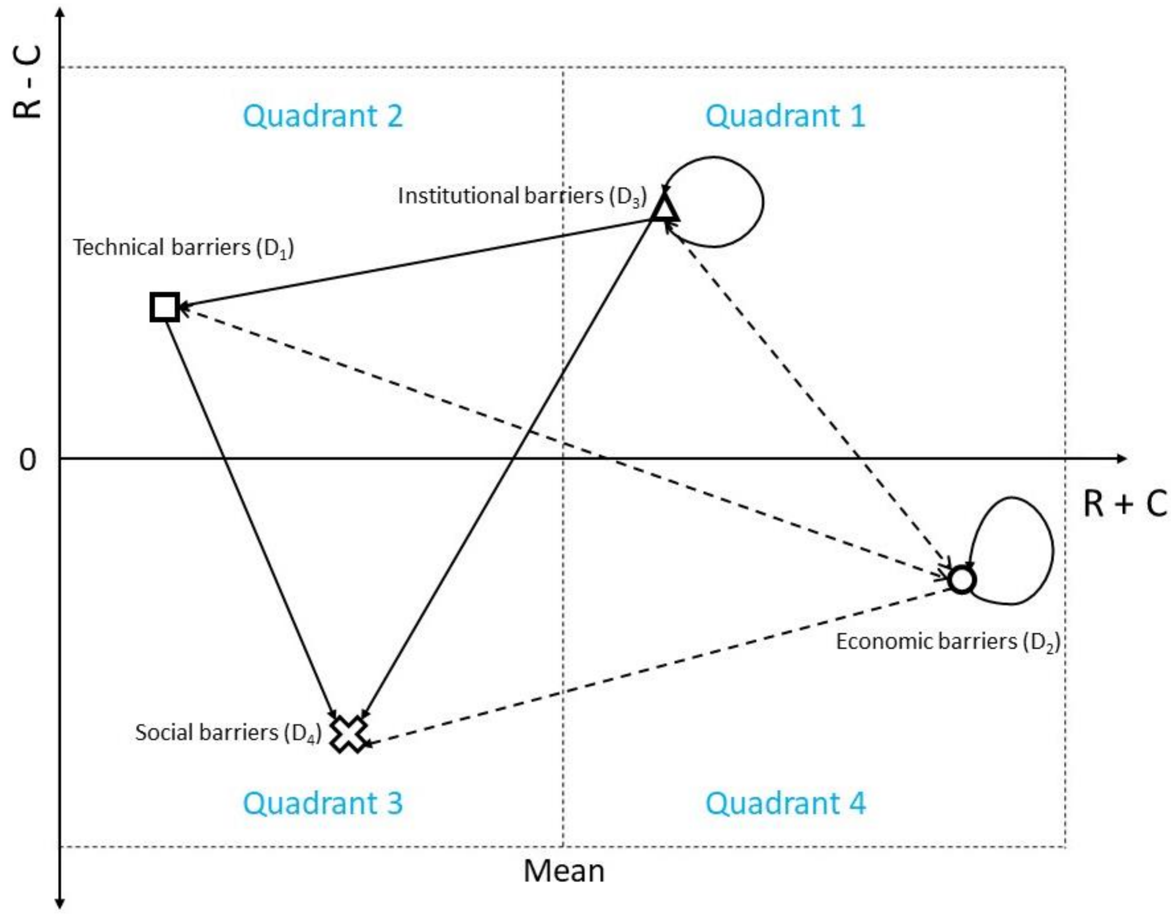


*Figure 14 The casual relationships between barrier groups*

Figure 14 shows the direct relationships between different barrier groups of institutional, economic, technical, and social. Following are the insights we gain from this:

- For the case of green hydrogen development in the country of UAE, the "Institutional barriers ($D_3$)" significantly affect the other three barriers, technical ($D_1$), economic ($D_2$), social ($D_4$). It also has a high value on the scale of prominence depicted by "R + C" value which places it rightly as a core factor affecting other barriers. Interestingly, it shares a bi-directional relationship with economic barriers and affects itself as well.
- The "Technical/Technological barriers" are shown to affect mainly the economic and social barriers. The cluster is in the quadrant for driving factors or autonomous givers and falls in the "cause group" of barriers. The technical barriers are rightfully autonomous in a way that they exhibit their own cycle of improving or upgrading the existing technology to a higher standard. Technical barriers also have a bi-directional relationship with economic barriers.
- The "Economic barriers ($D_2$)" fall in the "effect group" of barriers but have the highest value on the scale of prominence even higher than the institution barriers. This means the group of economic barriers have the highest influence amongst the effect group.

It also reinforces the fact that economic limitations are a derivative of the technology being implemented and the framework governing the development of the projects. However, these effects on the cost of technology generally get transferred to the end-consumer when adopting the hydrogen applications. All these relationships with other barrier groups are bi-directional showcasing how intertwined and impactful economic barriers are. The economic barriers also have an effect on itself. All these impacts on barrier groups rightfully place it in quadrant 4 representing impact factors.

- The "Social barriers ($D_4$)" in discussion are heavily influenced by the other three categories of barriers and thus fall the "effect group" of barriers. Similar to the technical barriers, the social barriers have their own learning curve and autonomous increase in awareness and understanding of technology over time. Although this process is heavily influenced by other factors like demonstration projects in the field of public transportation, availability of hydrogen refueling stations, increased safety of hydrogen, cheaper costs of adoption and even subsidies for the end-consumers.

From these relationships between barrier groups, we can conclude "institutional barriers" have the highest impact on the system due to higher value on the prominence scale (10.06) and having a ***causal*** effect on other barriers in the system. The "technical barriers" have the lowest prominence scale (9.2). This result is used in BWM section to calculate influential weights of the barriers.

However, this analysis does not exactly point towards the most impactful barrier or least impactful barrier and the exact relationships that exists between all the barriers. To identify these relationships, same steps in from this DEMATEL analysis are implemented.

## 5.2 Determining cause-effect relationships between barriers by DEMATEL

Steps 2 to 5 from section 2.4 for DEMATEL are followed to establish relationships between all identified 20 barriers. The values for direct relation matrix were obtained from 22 identified experts through questionnaire (refer Appendix B) and were averaged to get the average direct-relation matrix (A1) shown in Table 22.

| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | E1 | E2 | E3 | E4 | E5 | N1 | N2 | N3 | N4 | S1 | S2 | S3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.73 | 2.61 | 2.23 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.34 | 1.97 |
| T2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.79 | 3.53 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| T3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.17 | 2.43 | 1.48 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| T4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.74 | 1.43 | 3.61 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| T5 | 0.00 | 0.00 | 0.00 | 1.67 | 0.00 | 1.16 | 3.21 | 1.47 | 3.69 | 3.42 | 3.12 | 3.53 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.65 | 2.41 | 2.69 |
| T6 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.23 | 0.00 | 1.96 | 3.61 | 3.42 | 3.17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| T7 | 0.00 | 0.00 | 0.00 | 0.00 | 1.82 | 0.00 | 0.00 | 2.23 | 0.00 | 3.54 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| T8 | 0.00 | 1.43 | 0.00 | 0.00 | 0.00 | 0.00 | 3.65 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.17 | 1.43 | 3.26 |
| E1 | 0.00 | 0.00 | 0.00 | 3.12 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.34 | 3.21 | 3.17 | 3.59 | 0.00 | 2.37 | 0.00 | 0.00 | 3.74 | 2.84 | 2.61 |
| E2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.23 | 0.00 | 0.00 | 0.00 | 3.68 | 1.41 | 1.34 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| E3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.61 | 2.69 | 0.00 | 1.82 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.23 | 0.00 |
| E4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.61 | 0.92 | 3.54 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| E5 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| N1 | 3.17 | 0.00 | 0.00 | 1.82 | 0.00 | 0.00 | 0.00 | 1.09 | 3.85 | 3.42 | 3.53 | 1.16 | 1.43 | 0.00 | 2.06 | 3.61 | 3.53 | 1.33 | 3.61 | 3.12 |
| N2 | 0.00 | 2.21 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.69 | 0.00 | 2.78 | 1.94 | 1.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.21 | 3.21 |
| N3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.43 | 2.23 | 0.00 | 0.00 | 2.84 | 0.00 | 0.00 | 0.00 | 0.00 | 1.74 | 2.66 | 3.21 |
| N4 | 1.82 | 2.61 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.43 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.12 | 1.43 |
| S1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.73 | 2.33 | 3.06 | 0.00 | 0.00 | 0.00 | 2.03 | 0.00 | 0.00 | 0.00 | 3.21 | 3.74 |
| S2 | 3.42 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.23 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.26 |
| S3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

*Table 22 Average direct matrix ($A_2$)*

## 5.2.1 Calculating total influence matrix ($T_2$) for all barriers

We normalize the average direct matrix using the maximum value of the sum of rows and columns of the average direct-relation matrix (A2) to obtain normalized direct-relation matrix (D2) shown in Table 23

| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | E1 | E2 | E3 | E4 | E5 | N1 | N2 | N3 | N4 | S1 | S2 | S3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.07 | 0.07 | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.06 | 0.05 |
| T2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| T3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.09 | 0.07 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| T4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.04 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| T5 | 0.00 | 0.00 | 0.00 | 0.05 | 0.00 | 0.03 | 0.09 | 0.04 | 0.10 | 0.09 | 0.08 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.07 | 0.07 |
| T6 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.06 | 0.00 | 0.05 | 0.10 | 0.09 | 0.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| T7 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.00 | 0.00 | 0.06 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| T8 | 0.00 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.09 | 0.04 | 0.09 |
| E1 | 0.00 | 0.00 | 0.00 | 0.08 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.06 | 0.09 | 0.09 | 0.10 | 0.00 | 0.06 | 0.00 | 0.00 | 0.10 | 0.08 | 0.07 |
| E2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.06 | 0.00 | 0.00 | 0.00 | 0.10 | 0.04 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| E3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.07 | 0.07 | 0.00 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.06 | 0.00 |
| E4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.07 | 0.03 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| E5 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| N1 | 0.09 | 0.00 | 0.00 | 0.05 | 0.00 | 0.00 | 0.00 | 0.03 | 0.10 | 0.09 | 0.10 | 0.03 | 0.04 | 0.00 | 0.06 | 0.10 | 0.10 | 0.04 | 0.10 | 0.08 |
| N2 | 0.00 | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.00 | 0.08 | 0.05 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.06 | 0.09 |
| N3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.07 | 0.06 | 0.00 | 0.00 | 0.08 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.07 | 0.09 |
| N4 | 0.05 | 0.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.08 | 0.04 |
| S1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.07 | 0.06 | 0.08 | 0.00 | 0.00 | 0.00 | 0.06 | 0.00 | 0.00 | 0.00 | 0.09 | 0.10 |
| S2 | 0.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.09 |
| S3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

*Table 23 Normalized direct-relation matrix ($D_2$)*

The normalized matrix only provides us with the direct relationships between the barrier groups so to account for the indirect influences as well the total influence matrix is calculated. The indirect influence is the cascading effect one element would have on another but is caused by a third element and is denoted by $(I - D)^{-1}$.

The total influence matrix is represented by,

$$T = D(I - D)^{-1}$$

where I is a $20 \times 20$ identity matrix and D is the normalized direct-relation matrix. Solving for T we get,

| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | E1 | E2 | E3 | E4 | E5 | N1 | N2 | N3 | N4 | S1 | S2 | S3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T1** | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.01 | 0.08 | 0.08 | 0.08 | 0.01 | 0.01 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.08 | 0.07 |
| **T2** | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | 0.11 | 0.11 | 0.02 | 0.02 | 0.01 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 |
| **T3** | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.09 | 0.08 | 0.06 | 0.01 | 0.01 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 |
| **T4** | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.11 | 0.06 | 0.12 | 0.02 | 0.01 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.02 | 0.01 |
| **T5** | 0.01 | 0.00 | 0.00 | 0.06 | 0.01 | 0.03 | 0.10 | 0.05 | 0.14 | 0.14 | 0.14 | 0.12 | 0.02 | 0.00 | 0.02 | 0.00 | 0.00 | 0.12 | 0.10 | 0.11 |
| **T6** | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.07 | 0.01 | 0.07 | 0.12 | 0.12 | 0.10 | 0.01 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 |
| **T7** | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.00 | 0.02 | 0.06 | 0.01 | 0.11 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 |
| **T8** | 0.00 | 0.04 | 0.00 | 0.00 | 0.01 | 0.00 | 0.10 | 0.01 | 0.01 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.09 | 0.05 | 0.11 |
| **E1** | 0.01 | 0.00 | 0.00 | 0.09 | 0.00 | 0.00 | 0.01 | 0.01 | 0.04 | 0.09 | 0.13 | 0.10 | 0.11 | 0.00 | 0.07 | 0.00 | 0.00 | 0.11 | 0.10 | 0.10 |
| **E2** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.06 | 0.00 | 0.01 | 0.02 | 0.11 | 0.05 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 |
| **E3** | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | 0.08 | 0.08 | 0.02 | 0.06 | 0.01 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.07 | 0.01 |
| **E4** | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.08 | 0.04 | 0.11 | 0.01 | 0.01 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 |
| **E5** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **N1** | 0.11 | 0.01 | 0.00 | 0.06 | 0.00 | 0.00 | 0.01 | 0.04 | 0.15 | 0.14 | 0.15 | 0.06 | 0.07 | 0.00 | 0.07 | 0.10 | 0.10 | 0.06 | 0.15 | 0.14 |
| **N2** | 0.01 | 0.06 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.07 | 0.02 | 0.09 | 0.06 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.07 | 0.10 |
| **N3** | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.01 | 0.07 | 0.07 | 0.02 | 0.01 | 0.09 | 0.00 | 0.01 | 0.00 | 0.00 | 0.06 | 0.09 | 0.11 |
| **N4** | 0.06 | 0.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.04 | 0.01 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.09 | 0.06 |
| **S1** | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.01 | 0.09 | 0.08 | 0.11 | 0.02 | 0.01 | 0.00 | 0.06 | 0.00 | 0.00 | 0.01 | 0.11 | 0.13 |
| **S2** | 0.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.06 | 0.01 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.10 |
| **S3** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

*Table 24 Total influence matrix ($T_2$)*

From this we calculate “R” and “C” which are sum of rows and columns of the total influence matrix ($T_2$) respectively. The elements in the rows of this matrix represent the influence one barrier has on the others and the elements in the columns represent the effect other barriers have on it. These values would then be used to derive “R+C” defined as the prominence value representing the degree of influence and “R-C” defined as the net cause-and-effect value where the positive values are the cause variables and negative are the effect variables.

| | $R_i$ | $C_i$ | $R_i + C_i$ | $R_i - C_i$ |
|---|---|---|---|---|
| *T1* | 0.46 | 0.33 | 0.79 | 0.13 |
| *T2* | 0.33 | 0.21 | 0.54 | 0.12 |
| *T3* | 0.31 | 0.00 | 0.31 | 0.31 |
| *T4* | 0.39 | 0.29 | 0.68 | 0.10 |
| *T5* | 1.18 | 0.07 | 1.25 | 1.11 |
| *T6* | 0.56 | 0.03 | 0.59 | 0.52 |
| *T7* | 0.32 | 0.43 | 0.75 | -0.10 |
| *T8* | 0.47 | 0.32 | 0.79 | 0.15 |
| *E1* | 0.98 | 1.24 | 2.22 | -0.27 |
| *E2* | 0.31 | 1.28 | 1.59 | -0.97 |
| *E3* | 0.38 | 1.35 | 1.73 | -0.97 |
| *E4* | 0.31 | 0.69 | 1.00 | -0.39 |
| *E5* | 0.00 | 0.47 | 0.47 | -0.47 |
| *N1* | 1.43 | 0.00 | 1.43 | 1.43 |
| *N2* | 0.55 | 0.33 | 0.88 | 0.21 |
| *N3* | 0.55 | 0.10 | 0.65 | 0.45 |
| *N4* | 0.37 | 0.10 | 0.47 | 0.28 |
| *S1* | 0.69 | 0.54 | 1.23 | 0.16 |
| *S2* | 0.31 | 1.01 | 1.32 | -0.69 |
| *S3* | 0.00 | 1.10 | 1.10 | -1.10 |

*Table 25 Results of DEMATEL calculation for barriers*

From the values obtained in Table 25, we can now determine all the relationships between barriers by plotting them in the IRM quadrants as shown in Figure 15. The blue dots represent the technical barriers, the orange dots represent economic barriers, the green dots represent the institutional barriers, and the yellow dots represent the social barriers.

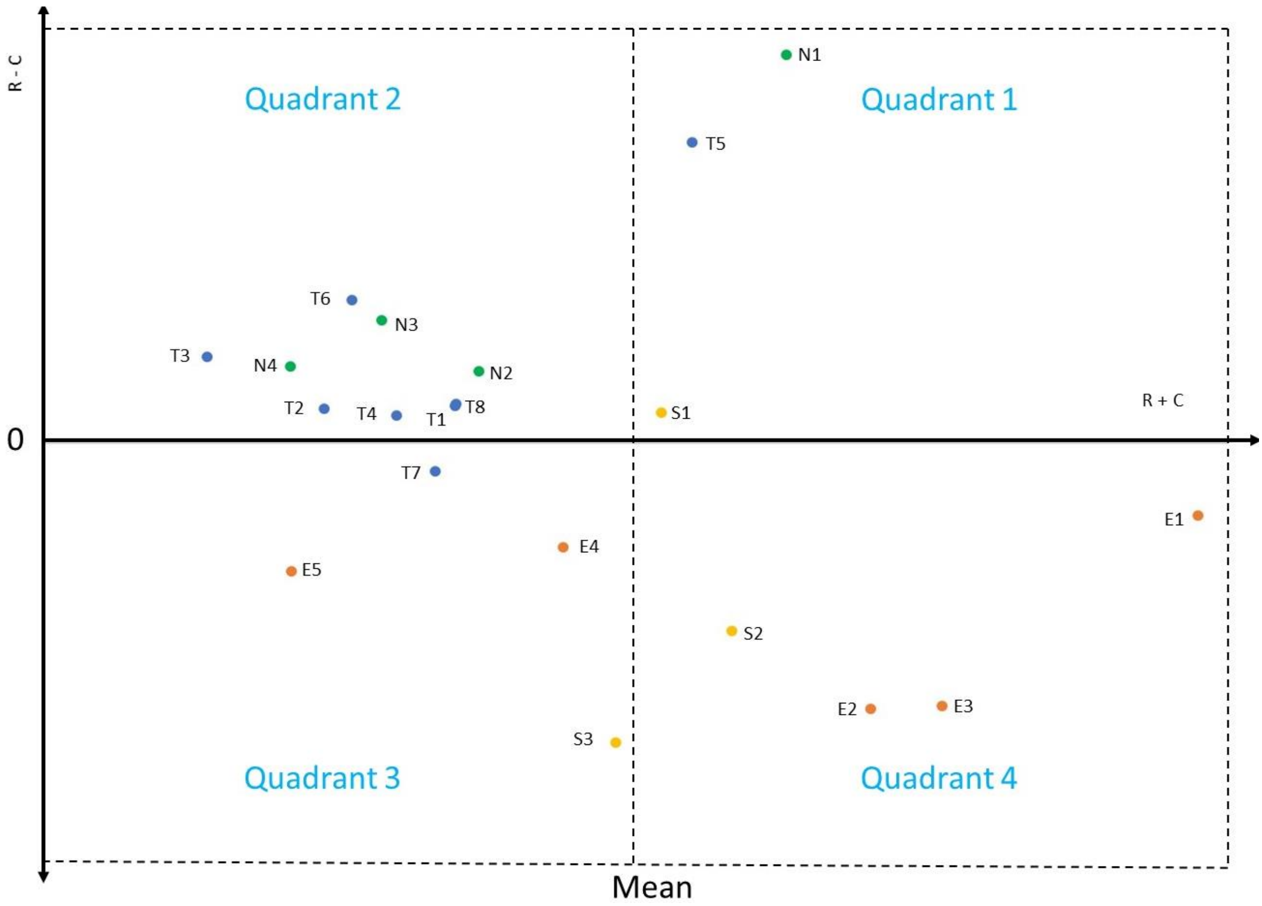


*Figure 15 Barriers to green hydrogen plotted in IRM*

From the values in Table 25 and influential relationship map in Figure 15, we can now establish the cause-effect groups of barriers and the best and worst criteria to determine weights of the barriers by implementing BWM. Following are the insights we gained:

- As can be seen from Figure 15, three barriers of lack of legislature for hydrogen ($N_1$), safety issue of hydrogen ($T_5$) and social acceptance of hydrogen applications ($S_1$) are located in Quadrant 1, which means they are cause barriers with high importance affecting majority of other barriers. Among them, lack of legislature for hydrogen ($N_1$) has the highest importance.
- A majority of technical barriers are located in Quadrant 2 namely; Low renewable energy penetration ($T_1$), Low efficiency of electrolysis ($T_2$), Renewable source of freshwater (desalination) ($T_3$), Shortage of hydrogen storage infrastructure ($T_4$), Blending with natural gas ($T_6$), Lack of skilled personnel and training institutions ($T_8$) reinforcing our previous findings (Figure 14) of them being autonomous givers or driving factors by exhibiting their own independent learning curve and technology maturity.
- The institutional barriers of Lack of privatization in energy sector ($N_2$), Lack of incentives, tax breaks and subsidies ($N_3$) and Lack of funding for research ($N_4$) are located in Quadrant 2, these barriers are mainly influenced by the barrier lack of

legislature for hydrogen ($N_1$) but they collectively influence other barriers in the system.

- Quadrant 3 houses the barriers of maintenance and repair network ($T_7$), Additional gas-grid injection costs ($E_4$), costs for carbon capture and storage ($E_5$) and Lack of awareness in society ($S_3$). These barriers come under the category of effect barriers with low importance, which are identified as non-critical barriers. However, they cannot be ignored since they do impact the system.
- Quadrant 4 includes effect barriers with high importance and mainly include economic barriers as they are highly influenced by technical, social, and institutional barriers. These barriers are High initial costs ($E_1$), High operational costs ($E_2$), High storage, transmission, and distribution costs ($E_3$) and Preference towards conventional fuels ($S_2$).
- Due to their high values of prominence and relations, lack of legislature for hydrogen ($N_1$), safety issue of hydrogen ($T_5$), Social acceptance of hydrogen applications ($S_1$), High initial costs ($E_1$), High operational costs ($E_2$), High storage, transmission, and distribution costs ($E_3$) and Preference towards conventional fuels ($S_2$) are identified to be the most-critical barriers to the development of green hydrogen in UAE.

The result from this analysis establishes the best and worst barriers in each individual category of technical, economic, institutional and social. The identified criteria are as follows:

- **For technical barriers**: Best – Safety issues of hydrogen ($T_5$) and Worst – Renewable source of freshwater ($T_3$)
- **For economic barriers**: Best – High initial investment ($E_1$) and Worst – Costs associated to carbon capture and storage ($E_5$)
- **For institutional barriers**: Best – Lack of legislature for hydrogen ($N_1$) and Worst – Lack of funding for research ($N_4$)
- **For social barriers**: Best – Preference towards conventional fuels ($S_2$) and Worst – Social acceptance of hydrogen applications ($S_1$)
- **For barrier groups**: Best – Institutional and Worst – Technical

These results would be used in the next section for implementing the BWM to obtain the order of priority to tackle the barriers.

### 5.2.2 Establishing interrelationships between all barriers

To eliminate the negligible relationships between dimensions, a threshold value θ needs to be determined. This is done to reduce the complexity of the relationship map by eliminating the relationships with a lower value of influence. At first the method of average all the elements of total influence matrix was used to calculate a threshold value of $\theta = 0.02$. However, this value added a lot more relationships than previously identified in Figure 14. Using that and the literature study as guidelines, a value of $\theta = 0.07$ is chosen. This value was chosen to establish a lower limit to address the relationships identified for different barrier groups. The resulting relationships are shown in Figure 16.

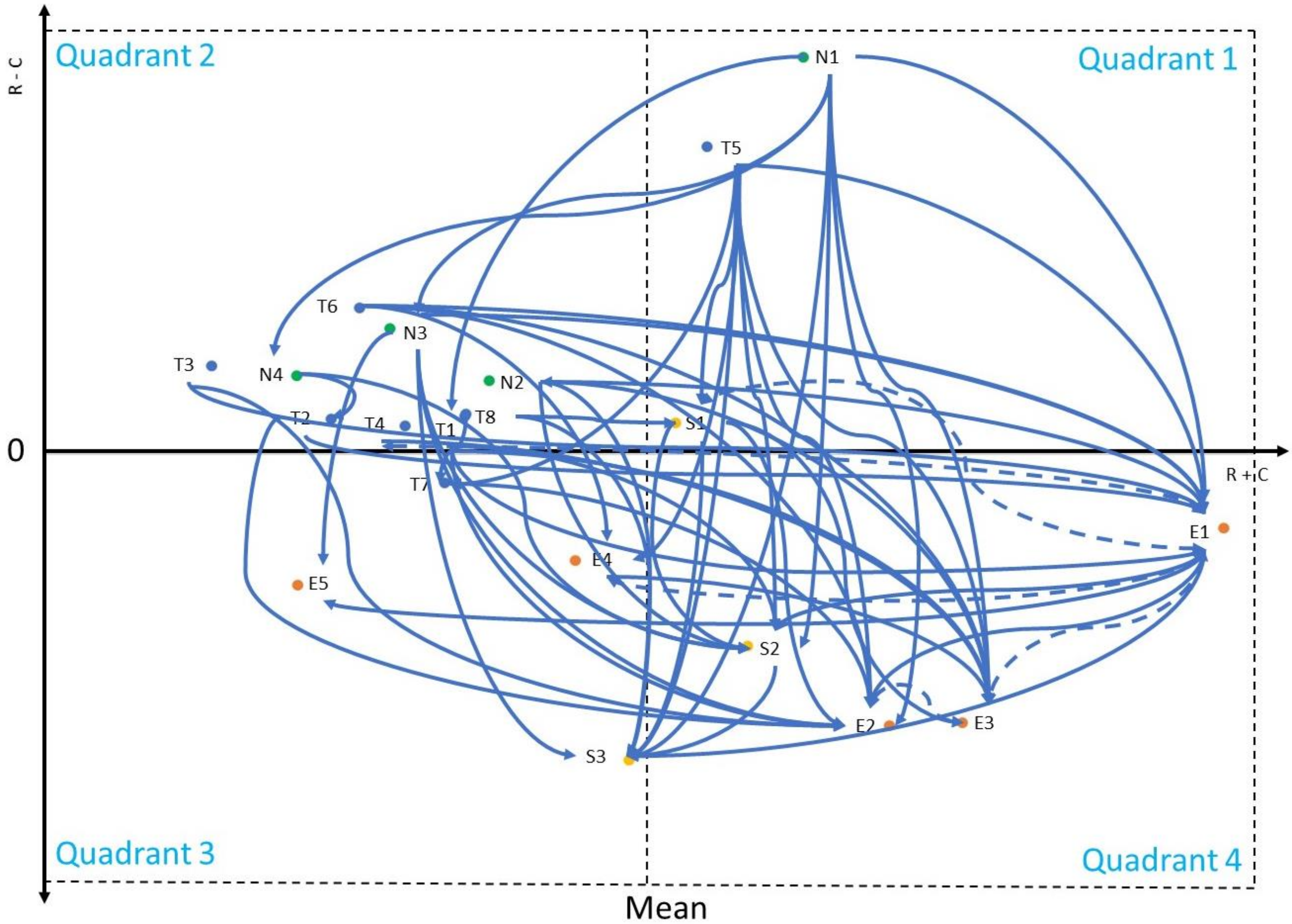


*Figure 16 Interrelationships between barriers to green hydrogen development in UAE*

As indicated previously in research methodology, a limitation of DEMATEL is being unable to reliably determine influential weights of the criteria. To overcome this limitation, we now determine the influential weights of the individual barriers through Best-Worst method using the results from DEMATEL in the following section.

## 5.3 Determining influential weights by Best-Worst Method

A total of 20 barriers have been identified for this research. Through DEMATEL analysis we have identified High initial cost (CAPEX) (E1) to be the “Best” factor or “most important” factor and Renewable source of freshwater (T3) to be the “Worst” factor or the “least important” factor.

The process of BWM uses only an integer scale of 1 to 9, considering the number of barriers we have is 20, the scale would not be effectively implemented. To overcome this issue, we split the analysis into 5 different BWM analysis namely: Technical barriers, Economic barriers, Institutional barriers, social barriers, and barrier groups.

### 5.3.1 Determining influential weights for all criteria

The best and worst criteria in the section are determined using the values of prominence ($R_i$ + $C_i$) from Table 25 and Table 21. The values assigned for influence in the BWM analysis are collected through a questionnaire filled in by 13 experts. The values assigned in this step are on a scale of 1 to 9 and denote the following: 1 – Equally important, 2 – Somewhat between equal and moderately important, 3 – Moderately more important, 4 – Somewhat between moderate and strong, 5 – Strongly more important, 6 – Somewhat between strong and very strong, 7 – Very strongly important than, 8 – Somewhat between very strong and absolutely more important, 9 – Absolutely more important. The weights for every individual collected response are calculated and then averaged to use in the analysis. Following are the calculations of steps 2 and 3 from section 2.4.

- **BWM 1: Best and worst criteria for technical barriers**

The best criteria is *"Safety issue of hydrogen ($T_5$)"* with a value of 1.24 and the worst criteria is *"Renewable source of freshwater ($T_3$)"* with a value of 0.31. The aim is to compare these two criteria with the other criteria in the group and assign a value for its preference over the other. For example, if the barrier T5 is "moderately more important than" barrier T7, then a value of "3" is assigned in the vector. Similarly, if barrier T6 is strongly more important than barrier T3, then a value of "5" is assigned.

Using these criteria, the Best-to-others (BO) vector and Others-to-worst (WO) vector are formulated as follows.

$$A_{B,Tech} = (4, 2, 9, 5, 1, 8, 7, 6)$$

$$A_{W,Tech} = (7, 8, 1, 5, 9, 2, 4, 6)^T$$

Where, $A_{B,Tech}$ and $A_{W,Tech}$ are the best and worst vectors for technical barriers respectively.

- **BWM 2: Best and worst criteria for economic barriers**

The best criteria is *"High initial costs ($E_1$)"* with a value of 2.21 and the worst criteria is *"Costs associated with carbon capture and storage ($E_5$)"* with a value of 0.47. The aim is to compare these two criteria with the other criteria in the group and assign a value for its preference over the other. For example, if the barrier E1 is "moderately more important than" barrier E2, then a value of "3" is assigned in the vector. Similarly, if barrier E3 is strongly more important than barrier E5, then a value of "5" is assigned.

Using these criteria, the Best-to-others (BO) vector and Others-to-worst (WO) vector are formulated as follows.

$$A_{B,Eco} = (1, 3, 2, 5, 4)$$

$$A_{W,Eco} = (5, 3, 4, 2, 1)^T$$

Where, $A_{B,Eco}$ and $A_{W,Eco}$ are the best and worst vectors for economic barriers respectively.

- **BWM 3: Best and worst criteria for institutional barriers**

The best criteria is *"Lack of legislature for hydrogen ($N_1$)"* with a value of 1.42 and the worst criteria is *"Lack of funding for research ($N_4$)"* with a value of 0.47. The aim is to compare these two criteria with the other criteria in the group and assign a value for its preference over the other. For example, if the barrier N1 is "moderately more important than" barrier N2, then a value of "3" is assigned in the vector. Similarly, if barrier N3 is strongly more important than barrier N4, then a value of "5" is assigned.

Using these criteria, the Best-to-others (BO) vector and Others-to-worst (WO) vector are formulated as follows.

$$A_{B,Inst} = (1, 5, 3, 7)$$

$$A_{W,Inst} = (7, 3, 5, 1)^T$$

Where, $A_{B,Inst}$ and $A_{W,Inst}$ are the best and worst vectors for institutional barriers respectively.

- **BWM 4: Best and worst criteria for social barriers**

The best criteria is *"Preference for conventional fuels ($S_2$)"* with a value of 1.32 and the worst criteria is *"Social acceptance of hydrogen applications ($S_1$)"* with a value of 1.1. The aim is to compare these two criteria with the other criteria in the group and assign a value for its preference over the other. For example, if the barrier S2 is "moderately more important than" barrier S3, then a value of "3" is assigned in the vector. Similarly, if barrier S3 is strongly more important than barrier S1, then a value of "5" is assigned.

Using these criteria, the Best-to-others (BO) vector and Others-to-worst (WO) vector are formulated as follows.

$$A_{B,Soc} = (7, 1, 3)$$

$$A_{W,Soc} = (1, 7, 4)^T$$

Where, $A_{B,Soc}$ and $A_{W,Soc}$ are the best and worst vectors for social barriers respectively.

- **BWM 5: Best and worst criteria for barrier groups**

The best criteria is *"Economic barriers ($D_2$)"* with a value of 10.59 and the worst criteria is *"Technical barriers ($T_1$)* with a value of 9.19.

Using these criteria, the Best-to-others (BO) vector and Others-to-worst (WO) vector are formulated as follows.

$$A_{B,Global} = (4, 2, 1, 3)$$

$$A_{W,Global} = (1, 3, 4, 2)^T$$

Where, $A_{B,Global}$ and $A_{W,Global}$ are the best and worst vectors for barrier groups.

### 5.3.2 Calculating aggregated weights of barriers and barrier groups

After establishing the best and worst vectors, the weights of barrier groups and barriers are calculated individually through the ratings obtained. These values are then used to calculate global weights and result in the ranking of barriers by the order of their influence on the system. Table 26 presents these values and ranking.

| Barrier groups | Weights of barrier groups | Consistency ratio of barrier groups | Barriers | Weights of barriers | Consistency ratio of barriers | Global weights | Ranking |
|---|---|---|---|---|---|---|---|
| **Technical barriers ($D_1$)** | 0.1035 | 0.0517 | T1 | 0.1119 | 0.096 | 0.0116 | **15** |
| | | | T2 | 0.2238 | | 0.0232 | **12** |
| | | | T3 | 0.0284 | | 0.0029 | **20** |
| | | | T4 | 0.0895 | | 0.0093 | **16** |
| | | | T5 | 0.3518 | | 0.0364 | **9** |
| | | | T6 | 0.056 | | 0.0058 | **19** |
| | | | T7 | 0.064 | | 0.0066 | **18** |
| | | | T8 | 0.0746 | | 0.0077 | **17** |
| **Economic barriers ($D_2$)** | 0.2586 | 0.0517 | E1 | 0.4098 | 0.082 | 0.1060 | **3** |
| | | | E2 | 0.1639 | | 0.0424 | **8** |
| | | | E3 | 0.2459 | | 0.0636 | **5** |
| | | | E4 | 0.0984 | | 0.0254 | **11** |
| | | | E5 | 0.0820 | | 0.0212 | **13** |
| **Institutional barriers ($D_3$)** | 0.4655 | 0.0517 | N1 | 0.5718 | 0.106 | 0.2662 | **1** |
| | | | N2 | 0.1356 | | 0.0631 | **6** |
| | | | N3 | 0.2261 | | 0.1052 | **4** |
| | | | N4 | 0.0665 | | 0.0310 | **10** |
| **Social barriers ($D_4$)** | 0.1724 | 0.0517 | S1 | 0.0833 | 0.083 | 0.0144 | **14** |
| | | | S2 | 0.6667 | | 0.1149 | **2** |
| | | | S3 | 0.2500 | | 0.0431 | **7** |

*Table 26 Influential weights for barrier groups and barriers*

## 5.4 Interpretation

In this section the data obtained in the barrier analysis is interpreted to answer the research questions.

### 5.4.1 Interpretation of DEMATEL analysis

After performing the DEMATEL analysis for both the barrier groups and individual barriers we were able to be identify all the relevant interrelationships that exist between them. These relationships were established Figure 14 and Figure 16 by using the values in Table 20, Table 21, Table 24 and Table 25. The insights gained would help answer the research sub-question: ***"How are the barriers to green hydrogen development in UAE interrelated?"***

- ***High initial investment ($E_1$)*** is the most impactful barrier to the development of green hydrogen in UAE, with a value of 2.21. It directly impacts the barriers of *High operation costs ($E_2$), Costs associated to carbon capture and storage ($E_5$), Lack of privatization ($N_2$), Preference towards conventional fuels ($S_2$) and lack of awareness in society ($S_3$).* Costs associated with a product is generally the most important parameter for both the normal citizen and a project developer, this cost component trickles down into operational costs. High CAPEX and an absence of government policies make it hard to justify the business case especially when competing against subsidized fossil fuels, which limits the private companies trying to enter the market without support from the government. High initial investment ($E_1$) shares a bi-directional relationship with *Shortage of hydrogen storage infrastructure ($T_4$), High storage, transmission, and distribution costs ($E_3$) and social acceptance of hydrogen applications ($S_1$).* These relationships are a result of the recurring circular effect of the high cost resulting in these aspects not developing, successful development of these aspects would reduce the initial costs by introducing more players in the economy adding competition and thereby reduction in costs.
- ***The lack of legislature for hydrogen ($N_1$)*** has the highest level of prominence amongst all cause barriers at 1.42. It directly affects *Low renewable energy penetration ($T_1$), High initial costs ($E_1$), High operation costs ($E_2$), High storage, transmission, and distribution costs ($E_3$), Lack of privatization ($N_2$), Lack of incentives, tax breaks and subsidies ($N_3$), Lack of funding for research ($N_4$), Preference towards conventional fuels ($S_2$) and lack of awareness in society ($S_3$).* We can interpret this as, the establishment of a governing framework would have a significant impact on the elimination of other barriers Amongst these, the most impacted barrier is *high initial investment ($E_1$)* with the value of 0.1543, which establishes the lack of a framework highly impacts the initial investment cost of setting up green hydrogen production facility. As indicated previously in literature and interviews, a lack of legislature for hydrogen greatly affects the development of green hydrogen. A lack of subsidies or incentives directly affects the development of renewable energy sources like PV and Wind; similarly, a lack of research funding deters opportunities for local researchers to contribute to the development. The institutional barriers have a significant impact on the economic barriers as with supportive legislature, the uptake of project development would increase due the cost viability, which would in turn affect the whole supply chain making it more affordable for further expansion. The lack of

privatization directly affects by limiting the competition in the market driving down the need for innovation; it also has an impact from the consumers perspective in limiting the options to choose from thus creating a monopoly.

- ***High storage, transmission, and distribution costs ($E_3$)*** has the second highest prominence among the economic barriers, with a value of 1.72. It shares two bi-directional relationships with High installation costs ($E_1$) and High operational costs ($E_2$). The relationship with $E_1$ is already explained above. With the installation of new and technologically superior storage, transmission, and distribution units, the costs for operation and maintenance would increase. The maintenance of these units would require specifically skilled people adding to the OPEX. But with the expansion of this network and planned maintenance, both the costs can be significantly reduced.
- ***Preference toward conventional fuels ($S_2$)*** has the highest level of prominence among all social barriers, with a value of 1.32. It directly affects the barriers of *Low renewable energy penetration ($T_1$) and lack of awareness in society ($S_3$).* Among these, *lack of awareness in society ($S_3$)* is impacted the most with a value of 0.1. Being a major petrostate for decades, the preference for using fossil fuels is deeply rooted in the society. This is further emphasized by the lost cost of fossil fuels and the electricity generated from them. A change in this lifestyle, especially the younger generation, can make major impacts on the increase in installed renewable capacity and also create awareness in the society for the alternative source of energy.
- ***Safety of hydrogen ($T_5$)*** has the highest level of prominence among all the technical barriers, with a value of 1.24. it directly impacts the barriers; Maintenance and repair network ($T_7$), *High initial costs ($E_1$), High operation costs ($E_2$), High storage, transmission, and distribution costs ($E_3$), Additional gas-grid injection costs ($E_4$), Social acceptance of hydrogen applications ($S_1$), Preference towards conventional fuels ($S_2$) and lack of awareness in society ($S_3$).* Among these, the costs for storage, transmission, and distribution are impact the most with a value of 0.144. The safety of hydrogen was indicated to be an important technical issue both in theory and interviews; with the formulation of safety guidelines and developing technology to demonstrate the safety publicly would help in gaining the confidence of end-consumers leading to the adoption of technology and creation of awareness amongst them. On the other hand, creation and implementation of safety standards would contribute to reducing the total costs in the entire supply chain.
- ***Social acceptance of hydrogen applications ($S_1$)*** falls in cause category with high importance and has a value of 1.18. It directly affects *High operation costs ($E_2$), High storage, transmission, and distribution costs ($E_3$), Preference towards conventional fuels ($S_2$) and lack of awareness in society ($S_3$).* The increase in demand of end-consumers for applications like hydrogen mobility and household consumption would force the supply side to keep up. These changes in the long turn would reduce the LCOE of hydrogen.

- ***High operational expenses ($E_2$)*** is another critical effect barrier identified. As it is a derivative of any expenses incurred after constructing new infrastructure for hydrogen, it is highly dependent on them. However, it has an effect on the repair and maintenance network ($T_7$) as with the establishment of new facilities in the green hydrogen supply chain, the operation costs for them would increase with an increase in requirement of a maintenance network.
- ***Lack of awareness ($S_3$)*** in the society is an autonomous effect barrier, which means it is dependent on the improvement of other barriers. Through the analysis we could establish the lack of awareness due to safety issues, lack of training institutions, high CAPEX, absence of framework, lack of privatization and a lack of subsidies.
- ***Additional gas-grid injection costs ($E_4$)*** is another effect barrier, caused by safety issues of hydrogen ($T_5$) especially pipe embrittlement and the problems caused by blending with natural gas. For transporting hydrogen over longer distances (inter-country) utilization of gas-grids is a viable option. However, due to highly corrosive nature of hydrogen, additional equipment must be added to the existing network. The costs of this additional equipment ($T_1$) also affects the grid injection costs.
- ***Lack of privatization in energy sector ($N_2$)*** is a cause barrier and is a result of the market being saturated by state-owned assets and companies. This barrier affects the costs of storage, transmission, and distribution ($E_3$), Preference of conventional fuels ($S_2$) and lack of awareness ($S_3$).
- ***Lack of incentives, tax breaks and subsidies ($N_3$)*** is another effect barrier as it mainly affects the high costs ($E_1$, $E_2$ and $E_5$) associated with the hydrogen projects. A lack of subsidies also impacts the social aspect by discouraging the move away from conventional fuels. Another important takeaway is the subsidies on fossil fuels severely impact the awareness around sustainability and curb the move towards green hydrogen.
- The other barriers of *low renewable energy penetration ($T_1$), Low efficiency of electrolysis ($T_2$), Renewable source of freshwater (desalination) ($T_3$), Shortage of hydrogen storage infrastructure ($T_4$), Blending with natural gas ($T_6$)* and *Lack of skilled personnel and training institutions ($T_8$)* are categorized as autonomous drivers, which means although they affect the economic and social aspects of green hydrogen development, they are not impacted by other factors and improve over time.

### 5.4.2 Results from DEMATEL - BWM

After establishing the relationships through DEMATEL, BWM was used to calculate the influential weights. These weights represent the impact of each barrier on the development of green hydrogen in UAE and thus provided an order in which they should be addressed for best results. Table 27 presents the cause-effect groups obtained from DEMATEL and the influential weights calculated through BWM.

| Barrier | Code | DEMATEL results | BWM results | |
|---|---|---|---|---|
| | | Cause-effect group | Ranking | Influential weight |
| Lack of legislature for hydrogen | N1 | **Cause** | **1** | 0.2662 |
| Preference towards conventional fuels | S2 | **Effect** | **2** | 0.1149 |
| High initial investment (CAPEX) | E1 | **Effect** | **3** | 0.1060 |
| Lack of incentives, tax breaks and subsidies | N3 | **Cause** | **4** | 0.1052 |
| High storage, transmission, and distribution costs | E3 | **Effect** | **5** | 0.0636 |
| Lack of privatization in energy sector | N2 | **Cause** | **6** | 0.0631 |
| Lack of awareness | S3 | **Effect** | **7** | 0.0431 |
| High Operational expenses (OPEX) | E2 | **Effect** | **8** | 0.0424 |
| Safety issues of hydrogen | T5 | **Cause** | **9** | 0.0364 |
| Lack of funding for research | N4 | **Cause** | **10** | 0.0310 |
| Additional gas-grid injection costs | E4 | **Effect** | **11** | 0.0254 |
| Low efficiency of electrolysis | T2 | **Cause** | **12** | 0.0232 |
| Costs associated to carbon capture and storage | E5 | **Effect** | **13** | 0.0212 |
| Social acceptance of hydrogen applications | S1 | **Cause** | **14** | 0.0144 |
| Low renewable energy penetration | T1 | **Cause** | **15** | 0.0116 |
| Shortage of hydrogen storage infrastructure | T4 | **Cause** | **16** | 0.0093 |
| Lack of skilled personnel and training institutions | T8 | **Cause** | **17** | 0.0077 |
| Maintenance and repair network | T7 | **Effect** | **18** | 0.0066 |
| Blending with natural gas | T6 | **Cause** | **19** | 0.0058 |
| Renewable source of freshwater (desalination) | T3 | **Cause** | **20** | 0.0029 |

*Table 27 Results from DEMATEL-BWM*

# Chapter 6: Discussion

The chapter begins with the discussing the methodology implemented and then the results obtained by its implementation. The results of this study are then discussed and compared with the existing literature, expert opinions and recommendations to overcome the identified barriers are provided. Furthermore, based on the limitations of this study, future recommendations are provided.

## 6.1 Combining DEMATEL and BWM

This research implements a combination of DEMATEL and BWM for analysing barriers to green hydrogen development in UAE. The DEMATEL model is initially used to establish interrelationships between different barrier groups of technical, economic, institutional and social. This was analysed to understand how the barrier groups interact and to serve as a guideline when calculating threshold value for individual barriers later in the process. On the other hand, these relationships between barrier groups provided the most prominent relationships to investigate. This analysis is also used to determine the best and worst barrier group category which is used in calculation for BWM. Next the barriers were assessed individually by implementing the DEMATEL method to establish the relationship between them. This was done to answer the sub-question 3: ***"How are the barriers interrelated?***

A total of 20 barriers are identified through literature and expert interviews. The data required for the analysis was collected through 22 experts and is presented in Appendix B. The outcomes of this DEMATEL analysis provides us with the interrelationships between all the barriers and plotting them in relationship map highlighting their causal or effect group $(R_i - C_j)$ and the value of prominence $(R_i + C_j)$; where $R_i$ is the value of the element in the $i$th row and $C_j$ is the value of element in the $j$th column of the Total influence matrix (T). If the value of $(R_i - C_i)$ is negative, the barrier falls under "effect" group and if the value of $(R_i + C_i)$ is positive then the barrier falls under "cause" group. Using this, the barriers are plotted in a digraph. To establish these relationships, as explained above, the prominent relationships established in the barrier group analysis alongside the literature study are used to implement a threshold value. The values in the total influence matrix (T) higher than the implemented threshold value are considered to ignore the minor effects. The result from this analysis establishes the best and worst barriers in each individual category of technical, economic, institutional and social. The identified criteria are as follows:

- **<u>For technical barriers</u>**: Best – Safety issues of hydrogen ($T_5$) and Worst – Renewable source of freshwater ($T_3$)
- **<u>For economic barriers</u>**: Best – High initial investment ($E_1$) and Worst – Costs associated to carbon capture and storage ($E_5$)

- **<u>For institutional barriers</u>**: Best – Lack of legislature for hydrogen ($N_1$) and Worst – Lack of funding for research ($N_4$)
- **<u>For social barriers</u>**: Best – Preference towards conventional fuels ($S_2$) and Worst – Social acceptance of hydrogen applications ($S_1$)
- **<u>For barrier groups</u>**: Best – Institutional and Worst – Technical

The part of identifying the best and worst criteria from DEMATEL for further BWM analysis is unique to this research. The traditional BWM requires selecting one best criterion and one worst criterion from within a set of criteria. Then the chosen criteria are compared in pairs to the other remaining criteria to formulate the "Best-to-Others" (BO) and "Others-to-Worst" (OW) vectors. However, there are two main requirements for this method to work, one is reaching a consensus with all interviewees regarding one best and one worst criterion and secondly, in a complex problem like the energy transition, where multiple criteria can affect one another, the best and worst criteria may be determined on face value and not considering if there are any factors causing it.

These limitations are best illustrated in the following example. While conducting interviews with experts for barrier identification in this research, at the start of the interview, the experts were asked to rank the barrier categories according to how they perceive their influence on the development of green hydrogen. Table 15 shows the ranking provided by the 7 interviewees. In this we can see, 4 out of 7 interviewees indicated "Economic barriers" to be the most influential barrier while only 1 interviewee indicated "Institutional barriers" to be the most impactful. However, when the same experts were asked to provide values for the questionnaire, the results obtained contradict the original opinion and can be seen in Table 26. The results obtained from the analysis show "institutional barriers" to be the most influential to the development of green hydrogen with a weight of 0.4655 as compared to a weight of 0.2586 of "economic barriers", which is a significant difference. This contradiction exists because the "economic barriers" are an effect of "institutional barriers" and not the most influential barrier affecting the development. The relationship between these two is established in the DEMATEL analysis of barrier groups prior to selection of best and worst criterion and is represented in the relationship map in Figure 14.

To summarize, there are two advantages of using DEMATEL and BWM in combination,

- The application of DEMATEL prior implementing BWM provides valuable insights into the interactions of criteria and can provide selection of the best and worst criteria which account for the interrelationships that exist between them. Thus, the methodology is able to capture both, the expert opinions to understand the influence and the underlying relationships between criteria.

- The methodology also eliminates the requirement of reaching a consensus with multiple decision-makers involved which could be more difficult to achieve with an increase in the number of decision-makers.

## 6.2 Interpretation of the barrier analysis

This section focuses on interpreting the results from the analysis for each barrier. The results are compared with the existing literature and recommendations are provided for overcoming the identified barriers.

**Lack of legislature for hydrogen ($N_1$)**

From Table 26, we can determine that *"lack of legislature for hydrogen ($N_1$)"* is ranked first with a criteria weight of 0.2662 (refer Table 27), which indicates the importance of addressing this factor for successful development of green hydrogen. Furthermore, in the DEMATEL analysis, it received a positive $(R_i - C_j)$ value of 1.42 (refer Table 25), indicating it is a ***causal*** barrier. As discussed in section 5.4, lack of framework has its effects on other barriers in the system. The main focus should be on creation of a framework focused on promoting and developing alternative sources of energy like solar PV, Wind and green hydrogen.

This was reinforced through literature by (Berger, 2021; Friedmann, 2021; Gielen, Boshell, et al., 2019; Munawwar & Ghedira, 2014; Netherlands Enterprise Agency, 2020), where the lack of a governing framework is considered to be a potential threat to establishing a green hydrogen economy in UAE. While discussing the important steps of energy transition, Gielen et al., mentions the importance of enabling frameworks for scaling up the development of applications for which technological solutions exists.

Recommendations: Formulation of a supporting policy framework would boost the development of green hydrogen. The formulation of this framework should take into consideration all the barriers a regulatory barrier would affect; these would include promoting installation of renewable energy, provision of grants/funds for installation of green hydrogen production facilities, establishing subsidy schemes or incentives and promote adoption of alternative sources of energy and move away from fossil fuels.

**Preference towards conventional fuels ($S_2$)**

The barrier *"preference for conventional fuels ($S_2$)"* received the second rank in the BWM analysis with a criteria weight of 0.1149 (refer Table 27), indicating attempts to change the current lifestyle by moving away from conventional fuels towards renewable energy sources would have a significant attempt on the development of green hydrogen. In the DEMATEL analysis, this factor received a negative $(R_i - C_j)$ value of -0.69 (refer Table 25), indicating it is an ***effect*** barrier. This barrier is affected by several other factors like safety of hydrogen ($T_5$), high investment costs ($E_1$), lack of privatization ($N_2$), lack of subsidies ($N_3$) lack of research funding ($N_4$), renewable energy penetration ($T_1$), awareness around hydrogen technology ($S_3$) and social acceptance of hydrogen applications ($S_1$). Therefore, attention to these barriers can have a positive impact on promoting sustainability in the society.

This was reinforced through the literature by (Netherlands Enterprise Agency, 2020) highlighting the challenge posed due to high dependence on fossil fuels of industrial, residential, transport and power sectors. Furthermore (Al Naqbi, Tsai, & Mezher, 2019) presents the market design required to achieve UAE's 2050 target, this research highlights the change needed in the cultural and behavioural aspects with regards to climate change to be able to increase clean energy use by 50%.

Recommendations: Promoting the applications of hydrogen alongside subsidies for using them is important. Phasing out subsidies for use of fossil fuels and implementation of carbon taxes is critical to encourage the use of hydrogen. Implementing small scale demonstration of hydrogen technology in applications like public transport can aid in influencing the citizens.

**High Initial investment ($E_1$)**

The barrier of *"high initial investment ($E_1$)"* is ranked third with a criteria weight of 0.1060 (refer Table 27), which indicates that a reduction in the initial investment can greatly boost the development of green hydrogen. In the DEMATEL analysis, it received a negative $(R_i - C_j)$ value of -0.27 (refer Table 25), indicating it is an ***effect*** barrier. The initial investment required for developing a successful hydrogen supply chain is heavily influence by the technology being used, its efficiency, the framework governing it and also the availability of subsidies or incentives. This barrier affects and is affected by multiple barriers and thus has complex relationships (refer Figure 16).

The challenges faced due to high initial investment cost is described by several researchers (Friedmann, 2021; Netherlands Enterprise Agency, 2020; Saccani et al., 2020). The interviewees in this research also highlighted economic barriers to be the most impactful. However, this research contradicts these findings by highlighting that the high initial costs are an effect of other institutional and technical barriers.

Recommendations: As highlighted previously, initial costs are affected by several factors in technical and institutional category. Promoting research in the field of hydrogen can contribute to improving the efficiency and lowering cost of electrolyser which is one of the most expensive components in the system. Another important factor is establishing funds for provision of incentives and subsidies to make a more attractive business case. When asked about overcoming the barrier of capital costs, Interviewee A mentions the following:

"Currently with the lack of government incentives or funds, the only way we can install new hydrogen production facilities is by creating a good business case for it. This business case in most situations is viable only if the project is a part of the EU partnerships where there is a possibility of applying for EU funds. UAE should focus on establishing similar funds to encourage the development."

**Lack of incentives, tax breaks and subsidies ($N_3$)**

The barrier of "*lack of incentives, tax breaks and subsidies ($N_3$)"* is ranked fourth with a criteria weight of 0.1052 (refer Table 27), as mentioned in high CAPEX, the provision of subsidies and incentives can have an important effect on the development of green hydrogen. In the DEMATEL analysis, it received a positive $(R_i - C_j)$ value of 0.45 (refer Table 25), indicating it is a ***causal*** barrier. The lack of incentives mainly affects the costs associated to the supply chain, promoting the energy transition by moving away from fossil fuel and increasing awareness of hydrogen technology.

The importance of having subsides and incentives targeting energy transition as a whole is highlighted by (Michaelowa & Butzengeiger, 2019) stating its massive indirect impact on increasing economic viability of hydrogen. Another important factor that needs to be considered is ending the subsidies on consumption of fossil fuels to increase the uptake on hydrogen as an alternative fuel.

Recommendations: Support schemes are required to incentivize the investments in the production of green hydrogen and the formulated framework for green hydrogen development must definitely include it.

**High storage, transmission and distribution costs ($E_3$)**

The barrier of *"High storage, transmission and distribution costs ($E_3$)"* is ranked fifth with a criteria weight of 0.0636 (refer Table 27), which indicates the development of the infrastructure surrounding the storage and transport would improve the efficiency of the whole supply chain and in the long term would reduce costs for transmission, distribution and storage. In the DEMATEL analysis, it received a negative $(R_i - C_j)$ value of -0.96 (refer Table 25), indicating it is an ***effect*** barrier which, similar to high investment costs, is affected by the technology used and the regulatory framework governing the development.

(Hjeij, Biçer, & Koç, 2021) looks into hydrogen strategy for the case of Qatar, which is another natural gas exporting country like UAE. The paper highlights the need for establishing the storage, transmission and distribution for facilitating the emerging green hydrogen market and meeting the potential demand for hydrogen.

Recommendations: Outlining investments in storage, transmission and distribution infrastructure and making the information available with transparency in required to increase the investments in production plants. Increase in private-public partnerships for the development of this infrastructure can aid in reducing the costs for the government.

**Lack of privatization ($N_2$)**

The barrier of "*lack of privatization ($N_2$)*" is ranked sixth with a criteria weight of 0.0631 (refer Table 27). In the DEMATEL analysis, it received a positive $(R_i - C_j)$ value of 0.26 (refer Table 25), indicating it is a ***causal*** barrier. This barrier has its effects on high storage, transmission and distribution costs, social preference towards fossil fuels and the awareness around hydrogen.

The market in UAE is dominated by state-owned companies or private companies with the government having a large share in them. (Halaoui, Ghazaly, Aly, Malek, & Samal, 2022) investigates the private sector participation in GCC states, the report focus on the problems created by the low private sector participation and policy changes to overcome them. The need for more private participation stems from the growing demand for public services and insufficient innovation and market competition. The expansion of private sector would reduce the economic stress on the state and can enable the sav

Recommendations: To encourage private investments in the hydrogen development sector, a legal framework encompassing the new laws or modification enabling private sector participation needs to be formulated.

**Lack of awareness ($S_3$)**

The barrier of "*lack of awareness ($S_3$)*" is ranked seventh with a criteria weight of 0.0431 (refer Table 27), as mentioned for the barrier of preference towards conventional fuels, encouraging the use of alternative fuels and creating awareness among the citizens about the benefits of the new technology has significant effects on the development of green hydrogen. In the DEMATEL analysis, it received a negative $(R_i - C_j)$ value of -1.1 (refer Table 25), indicating it is an ***effect*** barrier. The barrier is mainly affected by the safety of hydrogen, lack of a framework promoting the use of hydrogen and its applications and the deep-rooted dependence on fossil fuels.

Recommendations: Campaigns involving citizens or associations for the promotion or demonstration of the hydrogen applications should be mandatory to create awareness in the society. Addition of courses in the topics of sustainable energy and climate change in the curriculums of middle school or high schools to educate the upcoming generation.

**High operational cost ($E_2$)**

The barrier of "*high operational costs ($E_2$)*" is ranked eighth with a criteria weight of 0.0424 (refer Table 27). In the DEMATEL analysis, it received a negative $(R_i - C_j)$ value of -0.97 (refer Table 25), indicating it is a ***causal*** barrier. The operational costs are mainly affected by the initial costs as they are indicated as a fraction of the CAPEX. However, in a long term, availability of a reliable maintenance and repair network alongside people skilled in the technology.

Recommendations: Alongside the similar measures for reduction of initial investment costs, establishing training institutions for training people in the relevant skills for the maintenance and repair of hydrogen production plants.

**Safety issues of hydrogen ($T_5$)**

The barrier of "*safety issues of hydrogen ($T_5$)*" is ranked ninth with a criteria weight of 0.0364 (refer Table 27), the safety issues of hydrogen is the most influential technical barrier to the development of green hydrogen. In the DEMATEL analysis, it received a positive $(R_i - C_j)$ value of 1.10 (refer Table 25), indicating it is a ***causal*** barrier. The safety issues related to hydrogen due to its corrosive and flammable nature affects other barriers of the added costs in the initial investments, the costs to maintain the infrastructure, additional costs incurred to modify the gas network for transporting hydrogen and the social aspects of people adopting the hydrogen applications like mobility.

These results are reinforced by (Clerici & Furfari, 2021), which presents the challenges to the development of green hydrogen in 2021 and in 2050; the paper mentions the current high operation costs due to poorly defined safety standards and market regulations. It also highlights the need for upgrading the subsystems of existing gas infrastructure for transmission of green hydrogen.

Recommendations: As highlighted in the interviews, UAE is in the process of creating safety standards for consumer use, however, other ways to improve the safety are by advancement of the technology used for storing and transporting hydrogen and by having preventive maintenance schedules.

**Lack of funding for research ($N_4$)**

The barrier of "*lack of funding for research ($N_4$)*" is ranked tenth with a criteria weight of 0.0310 (refer Table 27), this barrier was highlighted by an interviewee who is a researcher in the field of energy transition in UAE. In the DEMATEL analysis, it received a positive $(R_i - C_j)$ value of 0.28 (refer Table 25), indicating it is a ***causal*** barrier. The interviewee mentioned the practice of relying on foreign research instead of promoting local research, this affects the availability of resources

Recommendations: Currently there is no specific research fund program in UAE and the funding is provided through the limited budget allocated to the public universities. Inclusion of a budget for promoting research, especially in the field of renewable energy would not only promote research in this field but also would strengthen the public awareness around the subjects

**Additional gas-grid injection costs ($E_4$)**

The barrier of "*Additional gas-grid injection costs ($E_4$)*" is ranked eleventh with a criteria weight of 0.0254 (refer Table 27), indicating the costs for modifying the existing gas infrastructure have a limited effect on the development of green hydrogen. In the DEMATEL analysis, it received a negative $(R_i - C_j)$ value of -0.38 (refer Table 25), indicating it is an ***effect*** barrier. These costs are affected by the safety issues of hydrogen and issues with blending with natural gas. Currently, in UAE, natural gas is mainly used for generating electricity and powering thermal desalination plants. In the short term, blending natural and green hydrogen for the same purposes can reduce the consumption of natural gas.

Recommendations: The reductions in the costs of modifying the infrastructure can be done by establishing partnerships with private firms so the cost to the state is reduced.

**Low efficiency of electrolysis ($T_2$)**

The barrier of "*Low efficiency of electrolysis ($T_2$)*" is ranked twelfth with a criteria weight of 0.0232 (refer Table 27), In the DEMATEL analysis, it received a positive $(R_i - C_j)$ value of 0.12 (refer Table 25), indicating it is a ***causal*** barrier. The low efficiency of electrolysers contribute to increase in the levelized costs of electricity (LCOE) but decreasing the total efficiency of the whole system and is reinforced by (Saccani et al., 2020).

Recommendations: Improvement in efficiency of technology is a learning curve and can be supported by promoting research in the field by providing funding for it.

Finally, the technical barriers of *low renewable energy penetration ($T_1$), shortage of hydrogen storage infrastructure ($T_4$), lack of skilled personnel and training institutions ($T_8$), maintenance and repair network ($T_7$), blending with natural gas ($T_6$) and renewable source of freshwater ($T_3$)* all fall into the ***casual*** group and the criteria weights of 0.0116, 0.0093, 0.0077, 0.0066, 0.0058 and 0.0029. All these barriers have relatively low impact on the development of green hydrogen. In the DEMATEL analysis, all these barriers fall in the 2$^{nd}$ quadrant of the relationship map, which means these barriers are of low importance and exhibit autonomous behaviour. This means that these barriers are mainly affected by factors outside the one's being studied in this research with improvements in efficiency of technologies being the most relevant one.

The next chapter is the concluding chapter that ties together the thesis. It answers the research questions established in the first chapter through the results of the barrier analysis. It also presents a few recommendations for future research in the same direction.

## 6.3 Limitations of the research

This study has the following limitations which are listed below, further recommendations for future research is also provided:

- The idea of green hydrogen development is a broad concept, and it is difficult to include everything owing to time limitations in the study. As a result, the scope of green hydrogen production is limited to Power-to-Hydrogen technology to enable more accurate inclusion of barriers.
- Due to the regional specific nature of the study and present pandemic situation, interviews and questionnaires were done online. This has impacted the quality of research as, only a limited number of interviews (7) could be organized in the limited timeframe, though a larger pool of experts was contacted.
- In the case of technical barriers, it was later realized that the analysis was unable to incorporate the factor of technology maturity and improving efficiency over a span of time.
- The study implements a combination of DEMATEL and BWM, where the best and worst criteria are derived from DEMATEL and not from the expert decisions. However, the limitation of using this method is that any errors or deviation in the values given by experts for DEMATEL are carried over to BWM analysis. This deviation in opinions can result in different outcomes.
- The barrier group interrelationships do not accurately account for all the relationships and can only act as the bare minimum threshold to identify individual relationships. For example, in the literature study and interviews, we established the "lack of skilled personnel and training institutions ($T_8$)" has an effect on the "availability of a repair and maintenance network ($T_7$)". This effect, however, cannot be seen in the relationship map of barrier groups. This is due to the low effect other technical barriers have on the barrier groups of economic, social and institutional; this lowers the net effect value of the whole group and thus is not represented in the analysis.
- The calculations for weights only include the values provided for BWM, however, a method that combines the values obtained by DEMATEL and BWM could provide more effective weights to the criteria and improve the methodology.
- The importance and relationships established in this research is time-sensitive and a similar study in future would yield different results.

## 6.4 Recommendations for future research

Below are some recommendations for any future research with a similar scope of research or same methodology approach:

- A focus for future research could be if the conclusions of this study can be generalized for other GCC states or other petrostates. This research could aid in creating a model that could be applied for petrostates to successfully develop infrastructure of green hydrogen.
- Another potential area of research could be implementing the methodology used in this research of DEMATEL-BWM to analyse factors with priorities and interrelationships.
- The importance and relationships of barriers are time-dependent and can change over time. A future study could analysis barriers in a dynamic frame of reference, making the results valid for an extended period of time.

# Chapter 7: Conclusion

The goal of this study was to identify and analyse the barriers to the development of green hydrogen in UAE. This investigation was motivated by two factors: First, the announcement of UAE's Energy Strategy 2050 with its intention of adding 50% of clean energy to the total energy mix and secondly, several reports and articles highlighting the potential of GCC states in the production of green hydrogen. However, knowledge gaps exist between these factors. Inspite of the highlighted potential for hydrogen production, UAE does not have a hydrogen strategy guiding the development of green hydrogen in the country. Additionally, the barriers to the development of green hydrogen in the context of UAE have not been studied before. This research aims to fill this gap by identifying the barriers for green hydrogen development in UAE and then understanding the interrelationships that exist between the barriers and finally ranking them in the order of which they should be addressed for successful development.

The comparison of data from two sources of literature and expert interviews helped to identify twenty barriers. This overview of barriers would serve as a foundational work for future research as it summarizes the barriers from technical, economic, institutional and social perspective, which has been a research gap as the barriers to green hydrogen development in UAE have not been studied previously (refer Table 17). This answers the first research question established in the first section, ***"What are the barriers for large-scale development of Green hydrogen technology in UAE?"***

For answering the second research question, **"*What are the most influential barriers to the development and what interrelationships exists between them?",*** a methodology implementing a combination of DEMATEL and BWM, two multi-criteria decision methods is used. This method is implemented to obtain two vital pieces of information; firstly, DEMATEL provides information on the interrelationships of barriers and identifies the best and worst criteria for implementing BWM. Secondly, the barriers are ranked on their influence on the system through BWM which provides us the order of priority the barriers should be tackled. Another novelty of this research is that the information perceived from DEMATEL helps in filtering out the criteria and overcoming the unintentional biasness added by the decision-makers while choosing the best and worst criteria, thus making the process convenient and reliable. The required values for implementing this methodology was collected via questionnaire from 22 identified experts (refer Appendix C). The identified barriers are mapped using DEMATEL highlighting their interrelationships with other barriers (refer Figure 16). These interrelationships help in categorizing the barrier into cause-and-effect groups while BWM helps in prioritizing the barriers.

From the DEMATEL-BWM analysis, the barriers of “lack of legislature for hydrogen”, “preference towards fossil fuels”, “high initial investment costs”, “lack of incentives, tax breaks and subsidies”, “high storage, transmission and distribution costs”, “lack of privatization” and “lack of awareness in society” are the highest priority factors. However, amongst these, only “lack of legislature for hydrogen”, “lack of incentives, tax breaks and subsidies” and “lack of privatization” are the causal factors. The outcomes of this research could possibly aid policymakers in UAE to decide where to concentrate their efforts for successful development of green hydrogen. The significant contributions of this research have been highlighted in the previous section, indicating this study would serve as a foundation for future research on the development of green hydrogen in UAE.

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# Chapter 9: Appendix A

## Responses for DEMATEL barrier groups

Following are the responses to the questionnaire collecting values for barrier groups.

- Respondent 1

| | Technical | Economic | Institutional | Social |
|---|---|---|---|---|
| **Technical** | 0 | 3 | 1 | 0 |
| **Economic** | 2 | 0 | 3 | 2 |
| **Institutional** | 3 | 3 | 0 | 3 |
| **Social** | 1 | 2 | 3 | 0 |

- Respondent 2

| | Technical | Economic | Institutional | Social |
|---|---|---|---|---|
| **Technical** | 0 | 4 | 3 | 4 |
| **Economic** | 4 | 0 | 3 | 2 |
| **Institutional** | 1 | 4 | 0 | 1 |
| **Social** | 4 | 3 | 3 | 0 |

- Respondent 3

| | Technical | Economic | Institutional | Social |
|---|---|---|---|---|
| **Technical** | 0 | 3 | 3 | 4 |
| **Economic** | 4 | 0 | 4 | 2 |
| **Institutional** | 3 | 3 | 0 | 4 |
| **Social** | 1 | 1 | 3 | 0 |

- Respondent 4

| | Technical | Economic | Institutional | Social |
|---|---|---|---|---|
| **Technical** | 0 | 3 | 3 | 1 |
| **Economic** | 1 | 0 | 3 | 2 |
| **Institutional** | 3 | 3 | 0 | 3 |
| **Social** | 4 | 4 | 4 | 0 |

- Respondent 5

| | Technical | Economic | Institutional | Social |
|---|---|---|---|---|
| **Technical** | 0 | 3 | 2 | 0 |
| **Economic** | 4 | 0 | 3 | 3 |
| **Institutional** | 3 | 4 | 0 | 1 |
| **Social** | 0 | 0 | 1 | 0 |

- Respondent 6

| | Technical | Economic | Institutional | Social |
|---|---|---|---|---|
| **Technical** | 0 | 3 | 1 | 4 |
| **Economic** | 3 | 0 | 3 | 3 |
| **Institutional** | 3 | 4 | 0 | 4 |
| **Social** | 2 | 0 | 4 | 0 |

- Respondent 7

| | Technical | Economic | Institutional | Social |
|---|---|---|---|---|
| **Technical** | 0 | 4 | 1 | 2 |
| **Economic** | 3 | 0 | 1 | 3 |
| **Institutional** | 2 | 2 | 0 | 2 |
| **Social** | 0 | 0 | 3 | 0 |

- Respondent 8

| | Technical | Economic | Institutional | Social |
|---|---|---|---|---|
| **Technical** | 0 | 4 | 0 | 3 |
| **Economic** | 1 | 0 | 1 | 4 |
| **Institutional** | 2 | 3 | 0 | 3 |
| **Social** | 2 | 2 | 2 | 0 |

- Respondent 9

| | Technical | Economic | Institutional | Social |
|---|---|---|---|---|
| **Technical** | 0 | 3 | 0 | 4 |
| **Economic** | 2 | 0 | 3 | 2 |
| **Institutional** | 1 | 4 | 0 | 2 |
| **Social** | 1 | 1 | 2 | 0 |

- Respondent 10

| | Technical | Economic | Institutional | Social |
|---|---|---|---|---|
| **Technical** | 0 | 4 | 1 | 2 |
| **Economic** | 3 | 0 | 1 | 2 |
| **Institutional** | 2 | 3 | 0 | 2 |
| **Social** | 0 | 2 | 3 | 0 |

- Respondent 11

| | Technical | Economic | Institutional | Social |
|---|---|---|---|---|
| **Technical** | 0 | 4 | 1 | 2 |
| **Economic** | 3 | 0 | 1 | 3 |
| **Institutional** | 2 | 4 | 0 | 4 |
| **Social** | 1 | 3 | 2 | 0 |

- Respondent 12

| | Technical | Economic | Institutional | Social |
|---|---|---|---|---|
| **Technical** | 0 | 4 | 2 | 4 |
| **Economic** | 1 | 0 | 2 | 2 |
| **Institutional** | 3 | 3 | 0 | 4 |
| **Social** | 3 | 2 | 2 | 0 |

- Respondent 13

| | Technical | Economic | Institutional | Social |
|---|---|---|---|---|
| **Technical** | 0 | 4 | 1 | 3 |
| **Economic** | 1 | 0 | 2 | 4 |
| **Institutional** | 2 | 3 | 0 | 4 |
| **Social** | 1 | 3 | 3 | 0 |

- Respondent 14

| | Technical | Economic | Institutional | Social |
|---|---|---|---|---|
| **Technical** | 0 | 4 | 1 | 2 |
| **Economic** | 2 | 0 | 3 | 4 |
| **Institutional** | 2 | 3 | 0 | 3 |
| **Social** | 2 | 1 | 3 | 0 |

- Respondent 15

| | Technical | Economic | Institutional | Social |
|---|---|---|---|---|
| **Technical** | 0 | 4 | 0 | 2 |
| **Economic** | 2 | 0 | 1 | 2 |
| **Institutional** | 2 | 4 | 0 | 3 |
| **Social** | 0 | 2 | 3 | 0 |

- Respondent 16

| | Technical | Economic | Institutional | Social |
|---|---|---|---|---|
| **Technical** | 0 | 3 | 0 | 3 |
| **Economic** | 3 | 0 | 1 | 3 |
| **Institutional** | 2 | 4 | 0 | 3 |
| **Social** | 0 | 1 | 2 | 0 |

- Respondent 17

| | Technical | Economic | Institutional | Social |
|---|---|---|---|---|
| **Technical** | 0 | 4 | 1 | 3 |
| **Economic** | 2 | 0 | 1 | 3 |
| **Institutional** | 2 | 4 | 0 | 3 |
| **Social** | 1 | 2 | 2 | 0 |

- Respondent 18

| | Technical | Economic | Institutional | Social |
|---|---|---|---|---|
| **Technical** | 0 | 3 | 1 | 2 |
| **Economic** | 3 | 0 | 1 | 2 |
| **Institutional** | 2 | 4 | 0 | 2 |
| **Social** | 1 | 2 | 2 | 0 |

- Respondent 19

| | Technical | Economic | Institutional | Social |
|---|---|---|---|---|
| **Technical** | 0 | 3 | 1 | 1 |
| **Economic** | 3 | 0 | 3 | 1 |
| **Institutional** | 2 | 3 | 0 | 3 |
| **Social** | 1 | 1 | 0 | 0 |

- Respondent 20

| | Technical | Economic | Institutional | Social |
|---|---|---|---|---|
| **Technical** | 0 | 4 | 1 | 3 |
| **Economic** | 2 | 0 | 1 | 4 |
| **Institutional** | 2 | 3 | 0 | 2 |
| **Social** | 1 | 1 | 3 | 0 |

- Respondent 21

| | Technical | Economic | Institutional | Social |
|---|---|---|---|---|
| **Technical** | 0 | 4 | 2 | 3 |
| **Economic** | 1 | 0 | 3 | 3 |
| **Institutional** | 2 | 3 | 0 | 3 |
| **Social** | 2 | 1 | 3 | 0 |

- Respondent 22

| | Technical | Economic | Institutional | Social |
|---|---|---|---|---|
| **Technical** | 0 | 3 | 1 | 2 |
| **Economic** | 1 | 0 | 3 | 4 |
| **Institutional** | 3 | 4 | 0 | 2 |
| **Social** | 0 | 1 | 3 | 0 |

# Chapter 10: Appendix B

## Responses for DEMATEL individual barriers

Following are the responses to the questionnaire collecting values for individual barrier influences

- Respondent 1

| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | E1 | E2 | E3 | E4 | E5 | N1 | N2 | N3 | N4 | S1 | S2 | S3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 3 |
| T2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T5 | 0 | 0 | 0 | 2 | 0 | 1 | 3 | 2 | 4 | 2 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 4 |
| T6 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 3 | 3 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T7 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 3 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T8 | 0 | 3 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 3 |
| E1 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 3 | 4 | 0 | 2 | 0 | 0 | 4 | 3 | 3 |
| E2 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 4 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 |
| E4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| N1 | 4 | 0 | 0 | 2 | 0 | 0 | 0 | 2 | 4 | 4 | 4 | 2 | 2 | 0 | 2 | 4 | 3 | 2 | 4 | 3 |
| N2 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 3 | 4 |
| N3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 3 | 2 | 3 |
| N4 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 |
| S1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 4 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 3 | 4 |
| S2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| S3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

- Respondent 2

| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | E1 | E2 | E3 | E4 | E5 | N1 | N2 | N3 | N4 | S1 | S2 | S3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 3 |
| T2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T5 | 0 | 0 | 0 | 2 | 0 | 1 | 3 | 1 | 3 | 3 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 4 | 3 | 3 |
| T6 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 4 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T7 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 3 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T8 | 0 | 2 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 3 |
| E1 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 2 | 3 | 0 | 3 | 0 | 0 | 4 | 4 | 2 |
| E2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 4 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |
| E4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| N1 | 2 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 4 | 3 | 2 | 1 | 1 | 0 | 2 | 4 | 4 | 1 | 4 | 2 |
| N2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 3 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 2 | 3 |
| N3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 3 | 2 | 4 |
| N4 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 |
| S1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 4 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 3 | 4 |
| S2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| S3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | E1 | E2 | E3 | E4 | E5 | N1 | N2 | N3 | N4 | S1 | S2 | S3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 |
| T2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T5 | 0 | 0 | 0 | 3 | 0 | 2 | 4 | 2 | 3 | 3 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 3 |
| T6 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 3 | 4 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T7 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 3 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T8 | 0 | 1 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 3 |
| E1 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 2 | 3 | 0 | 2 | 0 | 0 | 4 | 3 | 4 |
| E2 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 3 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |
| E4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| N1 | 4 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 4 | 4 | 3 | 1 | 1 | 0 | 2 | 3 | 3 | 1 | 3 | 3 |
| N2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 3 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 2 | 3 |
| N3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 2 | 3 | 3 |
| N4 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 |
| S1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 3 | 3 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 3 | 3 |
| S2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| S3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | E1 | E2 | E3 | E4 | E5 | N1 | N2 | N3 | N4 | S1 | S2 | S3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 |
| T2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T5 | 0 | 0 | 0 | 3 | 0 | 2 | 3 | 1 | 4 | 3 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 4 | 3 | 3 |
| T6 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 2 | 4 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T7 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 3 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T8 | 0 | 1 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 3 |
| E1 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 2 | 3 | 0 | 3 | 0 | 0 | 4 | 4 | 2 |
| E2 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 3 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| E4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| N1 | 3 | 0 | 0 | 2 | 0 | 0 | 0 | 1 | 4 | 3 | 3 | 1 | 1 | 0 | 2 | 3 | 3 | 2 | 4 | 3 |
| N2 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 3 |
| N3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 2 | 3 | 4 |
| N4 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 2 |
| S1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 3 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 3 | 4 |
| S2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| S3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | E1 | E2 | E3 | E4 | E5 | N1 | N2 | N3 | N4 | S1 | S2 | S3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 |
| T2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T5 | 0 | 0 | 0 | 2 | 0 | 1 | 4 | 2 | 4 | 3 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 3 |
| T6 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 3 | 3 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T7 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 3 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T8 | 0 | 2 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 3 |
| E1 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 2 | 3 | 0 | 2 | 0 | 0 | 3 | 2 | 3 |
| E2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 4 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |
| E4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| N1 | 3 | 0 | 0 | 3 | 0 | 0 | 0 | 2 | 3 | 4 | 4 | 2 | 2 | 0 | 1 | 4 | 4 | 2 | 3 | 2 |
| N2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 2 | 2 |
| N3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 3 | 3 |
| N4 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 |
| S1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 3 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 4 | 4 |
| S2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| S3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | E1 | E2 | E3 | E4 | E5 | N1 | N2 | N3 | N4 | S1 | S2 | S3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 4 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 |
| T2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T5 | 0 | 0 | 0 | 3 | 0 | 2 | 3 | 1 | 3 | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 4 | 3 | 3 |
| T6 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 2 | 4 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T7 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 3 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T8 | 0 | 1 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 3 |
| E1 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 2 | 4 | 4 | 3 | 0 | 2 | 0 | 0 | 4 | 3 | 2 |
| E2 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 3 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |
| E4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| N1 | 4 | 0 | 0 | 1 | 0 | 0 | 0 | 2 | 4 | 2 | 3 | 2 | 2 | 0 | 3 | 3 | 3 | 2 | 4 | 3 |
| N2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 3 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 3 |
| N3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 2 | 2 | 2 |
| N4 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 |
| S1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 3 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 3 | 3 |
| S2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| S3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | E1 | E2 | E3 | E4 | E5 | N1 | N2 | N3 | N4 | S1 | S2 | S3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T1** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| **T2** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T4** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T5** | 0 | 0 | 0 | 1 | 0 | 1 | 4 | 1 | 4 | 4 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 4 | 1 | 2 |
| **T6** | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 2 | 4 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T7** | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 3 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T8** | 0 | 1 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 1 | 3 |
| **E1** | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 3 | 4 | 4 | 3 | 0 | 2 | 0 | 0 | 4 | 3 | 2 |
| **E2** | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 3 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **E3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 |
| **E4** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **E5** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **N1** | 4 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 4 | 3 | 4 | 1 | 2 | 0 | 3 | 3 | 3 | 0 | 3 | 4 |
| **N2** | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 4 |
| **N3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 1 | 3 | 3 |
| **N4** | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 2 |
| **S1** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 4 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 3 | 4 |
| **S2** | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| **S3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | E1 | E2 | E3 | E4 | E5 | N1 | N2 | N3 | N4 | S1 | S2 | S3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T1** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 4 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 |
| **T2** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T4** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T5** | 0 | 0 | 0 | 2 | 0 | 1 | 3 | 1 | 3 | 3 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 3 |
| **T6** | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 2 | 3 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T7** | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 3 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T8** | 0 | 2 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 4 |
| **E1** | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 3 | 4 | 0 | 3 | 0 | 0 | 4 | 3 | 3 |
| **E2** | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 4 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **E3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 |
| **E4** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **E5** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **N1** | 3 | 0 | 0 | 1 | 0 | 0 | 0 | 2 | 4 | 3 | 3 | 2 | 2 | 0 | 2 | 4 | 4 | 1 | 4 | 3 |
| **N2** | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 3 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 2 | 3 |
| **N3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 2 | 3 | 4 |
| **N4** | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 |
| **S1** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 3 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 4 | 3 |
| **S2** | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| **S3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | E1 | E2 | E3 | E4 | E5 | N1 | N2 | N3 | N4 | S1 | S2 | S3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T1** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 |
| **T2** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T4** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T5** | 0 | 0 | 0 | 1 | 0 | 1 | 3 | 0 | 4 | 3 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 3 |
| **T6** | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 1 | 3 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T7** | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 2 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T8** | 0 | 1 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 3 |
| **E1** | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 3 | 4 | 0 | 2 | 0 | 0 | 3 | 3 | 2 |
| **E2** | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **E3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |
| **E4** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **E5** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **N1** | 4 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 4 | 2 | 3 | 1 | 0 | 0 | 3 | 4 | 4 | 1 | 4 | 3 |
| **N2** | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 3 |
| **N3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 2 | 4 |
| **N4** | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 |
| **S1** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 2 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 3 | 4 |
| **S2** | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| **S3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | E1 | E2 | E3 | E4 | E5 | N1 | N2 | N3 | N4 | S1 | S2 | S3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T1** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 |
| **T2** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T4** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T5** | 0 | 0 | 0 | 1 | 0 | 1 | 3 | 2 | 3 | 4 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 4 | 3 | 4 |
| **T6** | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 3 | 4 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T7** | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 3 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T8** | 0 | 1 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 4 |
| **E1** | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 2 | 4 | 2 | 4 | 0 | 2 | 0 | 0 | 4 | 2 | 3 |
| **E2** | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 4 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **E3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| **E4** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **E5** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **N1** | 3 | 0 | 0 | 2 | 0 | 0 | 0 | 1 | 4 | 4 | 4 | 1 | 2 | 0 | 2 | 3 | 4 | 2 | 3 | 3 |
| **N2** | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 4 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 3 |
| **N3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 2 | 3 | 3 |
| **N4** | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 |
| **S1** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 3 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 3 | 4 |
| **S2** | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| **S3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | E1 | E2 | E3 | E4 | E5 | N1 | N2 | N3 | N4 | S1 | S2 | S3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 |
| T2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T5 | 0 | 0 | 0 | 1 | 0 | 1 | 3 | 2 | 4 | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 4 | 3 | 4 |
| T6 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 3 | 4 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T7 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 3 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T8 | 0 | 1 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 4 |
| E1 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 3 | 4 | 4 | 3 | 0 | 3 | 0 | 0 | 4 | 2 | 3 |
| E2 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 4 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |
| E4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| N1 | 4 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 4 | 3 | 4 | 1 | 1 | 0 | 2 | 4 | 3 | 1 | 3 | 4 |
| N2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 3 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 4 |
| N3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 3 | 3 |
| N4 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 |
| S1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 3 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 3 | 4 |
| S2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| S3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | E1 | E2 | E3 | E4 | E5 | N1 | N2 | N3 | N4 | S1 | S2 | S3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 |
| T2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T5 | 0 | 0 | 0 | 2 | 0 | 1 | 3 | 1 | 4 | 4 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 4 | 2 | 2 |
| T6 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 1 | 4 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T7 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 2 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T8 | 0 | 2 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 3 |
| E1 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 3 | 4 | 4 | 3 | 0 | 2 | 0 | 0 | 4 | 3 | 2 |
| E2 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 3 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 |
| E4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| N1 | 2 | 0 | 0 | 1 | 0 | 0 | 0 | 2 | 4 | 4 | 4 | 2 | 2 | 0 | 2 | 4 | 4 | 1 | 4 | 4 |
| N2 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 3 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 2 | 4 |
| N3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 1 | 2 | 4 |
| N4 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 |
| S1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 3 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 2 | 3 |
| S2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| S3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | E1 | E2 | E3 | E4 | E5 | N1 | N2 | N3 | N4 | S1 | S2 | S3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T1** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 |
| **T2** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T4** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T5** | 0 | 0 | 0 | 2 | 0 | 1 | 4 | 2 | 3 | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 4 | 2 | 2 |
| **T6** | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T7** | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 3 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T8** | 0 | 2 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 2 |
| **E1** | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 2 | 4 | 4 | 4 | 0 | 2 | 0 | 0 | 4 | 3 | 2 |
| **E2** | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 4 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **E3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 |
| **E4** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **E5** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **N1** | 3 | 0 | 0 | 2 | 0 | 0 | 0 | 2 | 3 | 3 | 4 | 2 | 2 | 0 | 2 | 4 | 4 | 1 | 4 | 2 |
| **N2** | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 3 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 2 | 2 |
| **N3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 3 | 3 |
| **N4** | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 |
| **S1** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 3 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 3 | 4 |
| **S2** | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| **S3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | E1 | E2 | E3 | E4 | E5 | N1 | N2 | N3 | N4 | S1 | S2 | S3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T1** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 |
| **T2** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T4** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T5** | 0 | 0 | 0 | 1 | 0 | 1 | 4 | 2 | 4 | 3 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 2 |
| **T6** | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 3 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T7** | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 3 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T8** | 0 | 1 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 1 | 3 |
| **E1** | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 3 | 4 | 0 | 2 | 0 | 0 | 4 | 3 | 4 |
| **E2** | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 4 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **E3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |
| **E4** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **E5** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **N1** | 3 | 0 | 0 | 2 | 0 | 0 | 0 | 1 | 4 | 3 | 4 | 1 | 1 | 0 | 3 | 3 | 4 | 1 | 3 | 2 |
| **N2** | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 3 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 2 |
| **N3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 2 | 2 | 3 |
| **N4** | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 |
| **S1** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 2 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 3 | 4 |
| **S2** | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| **S3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | E1 | E2 | E3 | E4 | E5 | N1 | N2 | N3 | N4 | S1 | S2 | S3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 |
| T2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T5 | 0 | 0 | 0 | 1 | 0 | 1 | 3 | 2 | 3 | 4 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 4 | 3 | 3 |
| T6 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T7 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 3 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T8 | 0 | 1 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 3 |
| E1 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 2 | 4 | 4 | 4 | 0 | 3 | 0 | 0 | 4 | 3 | 3 |
| E2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 4 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |
| E4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| N1 | 3 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 4 | 4 | 4 | 1 | 1 | 0 | 1 | 3 | 4 | 1 | 3 | 4 |
| N2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 3 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 3 | 4 |
| N3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 2 | 3 | 3 |
| N4 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 1 |
| S1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 4 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 4 | 4 |
| S2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| S3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | E1 | E2 | E3 | E4 | E5 | N1 | N2 | N3 | N4 | S1 | S2 | S3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 |
| T2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T5 | 0 | 0 | 0 | 2 | 0 | 1 | 2 | 1 | 4 | 3 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 4 | 2 | 2 |
| T6 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 1 | 3 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T7 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T8 | 0 | 2 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 1 | 4 |
| E1 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 3 | 4 | 0 | 3 | 0 | 0 | 4 | 3 | 3 |
| E2 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 4 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |
| E4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| N1 | 4 | 0 | 0 | 2 | 0 | 0 | 0 | 1 | 4 | 3 | 4 | 1 | 2 | 0 | 2 | 3 | 3 | 1 | 3 | 3 |
| N2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 3 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 3 | 3 |
| N3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 2 | 4 | 4 |
| N4 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 |
| S1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 2 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 4 | 3 |
| S2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| S3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | E1 | E2 | E3 | E4 | E5 | N1 | N2 | N3 | N4 | S1 | S2 | S3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 |
| T2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T5 | 0 | 0 | 0 | 1 | 0 | 1 | 3 | 2 | 4 | 3 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 2 |
| T6 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 3 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T7 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T8 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 4 |
| E1 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 3 | 4 | 0 | 3 | 0 | 0 | 3 | 2 | 3 |
| E2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 4 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| E4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| N1 | 3 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 4 | 4 | 4 | 0 | 1 | 0 | 2 | 4 | 3 | 1 | 3 | 2 |
| N2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 3 |
| N3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 2 | 2 | 3 |
| N4 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 |
| S1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 4 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 3 | 4 |
| S2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| S3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | E1 | E2 | E3 | E4 | E5 | N1 | N2 | N3 | N4 | S1 | S2 | S3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 |
| T2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T5 | 0 | 0 | 0 | 1 | 0 | 1 | 4 | 2 | 4 | 3 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 3 |
| T6 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 3 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T7 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T8 | 0 | 1 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 4 |
| E1 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 3 | 4 | 0 | 2 | 0 | 0 | 3 | 3 | 2 |
| E2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 3 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 |
| E4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| N1 | 3 | 0 | 0 | 4 | 0 | 0 | 0 | 1 | 4 | 4 | 3 | 1 | 1 | 0 | 2 | 4 | 3 | 1 | 4 | 4 |
| N2 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 3 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 3 |
| N3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 2 | 3 | 3 |
| N4 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 |
| S1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 3 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 3 | 4 |
| S2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| S3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | E1 | E2 | E3 | E4 | E5 | N1 | N2 | N3 | N4 | S1 | S2 | S3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 |
| T2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T5 | 0 | 0 | 0 | 2 | 0 | 1 | 4 | 1 | 4 | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 4 | 2 | 2 |
| T6 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T7 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T8 | 0 | 1 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 3 |
| E1 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 4 | 4 | 3 | 0 | 3 | 0 | 0 | 3 | 2 | 2 |
| E2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 4 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |
| E4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| N1 | 3 | 0 | 0 | 3 | 0 | 0 | 0 | 1 | 4 | 4 | 4 | 2 | 2 | 0 | 2 | 4 | 4 | 2 | 4 | 4 |
| N2 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 3 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 3 | 4 |
| N3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 1 | 2 | 4 |
| N4 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 1 |
| S1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 2 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 3 | 4 |
| S2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| S3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | E1 | E2 | E3 | E4 | E5 | N1 | N2 | N3 | N4 | S1 | S2 | S3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 |
| T2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T5 | 0 | 0 | 0 | 1 | 0 | 1 | 3 | 1 | 4 | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 4 | 1 | 1 |
| T6 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T7 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T8 | 0 | 1 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 1 | 3 |
| E1 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 2 | 4 | 4 | 4 | 0 | 2 | 0 | 0 | 4 | 3 | 3 |
| E2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 3 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |
| E4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| N1 | 4 | 0 | 0 | 3 | 0 | 0 | 0 | 1 | 4 | 3 | 3 | 0 | 1 | 0 | 2 | 3 | 4 | 1 | 4 | 4 |
| N2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 3 | 4 |
| N3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 3 | 4 |
| N4 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 2 |
| S1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 4 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 3 | 4 |
| S2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| S3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | E1 | E2 | E3 | E4 | E5 | N1 | N2 | N3 | N4 | S1 | S2 | S3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T1** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 |
| **T2** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T4** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T5** | 0 | 0 | 0 | 1 | 0 | 1 | 2 | 2 | 4 | 3 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 4 | 2 | 2 |
| **T6** | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 3 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T7** | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T8** | 0 | 1 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 2 | 4 |
| **E1** | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 3 | 4 | 0 | 2 | 0 | 0 | 4 | 3 | 2 |
| **E2** | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 4 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **E3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 |
| **E4** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **E5** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **N1** | 3 | 0 | 0 | 2 | 0 | 0 | 0 | 1 | 3 | 4 | 4 | 1 | 1 | 0 | 2 | 4 | 3 | 2 | 4 | 3 |
| **N2** | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 3 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 3 |
| **N3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 2 | 3 | 2 |
| **N4** | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 |
| **S1** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 2 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 4 | 4 |
| **S2** | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| **S3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | E1 | E2 | E3 | E4 | E5 | N1 | N2 | N3 | N4 | S1 | S2 | S3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T1** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 |
| **T2** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T4** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T5** | 0 | 0 | 0 | 2 | 0 | 2 | 3 | 1 | 4 | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 4 | 3 | 3 |
| **T6** | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T7** | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T8** | 0 | 3 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 3 |
| **E1** | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 3 | 4 | 4 | 4 | 0 | 2 | 0 | 0 | 3 | 2 | 2 |
| **E2** | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 4 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **E3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 |
| **E4** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **E5** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **N1** | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 4 | 4 | 3 | 0 | 1 | 0 | 1 | 4 | 4 | 2 | 4 | 4 |
| **N2** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 3 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 3 | 4 |
| **N3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 2 | 3 | 2 |
| **N4** | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 |
| **S1** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 3 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 4 | 3 |
| **S2** | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| **S3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

# Chapter 11: Appendix C

**Profiles of the questionnaire respondents**

| Respondent no. | Description | Location |
|---|---|---|
| **1** | A recent graduate in energy sciences working in green hydrogen and renewable energy development in UAE | UAE |
| **2** | An experienced business owner focussed on developing green hydrogen facilities in the region of MENA | UAE |
| **3** | A highly experienced safety auditor and member of government human resources (FAHR) | UAE |
| **4** | An academic researcher in the field of accelerating energy transition in the middle east | UAE |
| **5** | An academic researcher in the field of membrane technology in hydrogen electrolysers | UAE |
| **6** | Former member of the UAE government involved in the planning of energy strategies | UAE |
| **7** | An experienced professional working in the sales division for hydrogen mobility in UAE | UAE |
| **8** | A citizen of the society interested in owning a hydrogen car at the EXPO 2020 | UAE |
| **9** | A young engineer working in power-to-technology division in MNC | UAE |
| **10** | A consultant in energy storage and hydrogen development at an MNC | UAE |
| **11** | An academic researcher in the field of energy transition frameworks | UAE |
| **12** | A business developer in the sector of renewable energy assets | UAE |
| **13** | An engineer responsible for operations and maintenance for multiple desalination plants | UAE |
| **14** | A business developer in the field of solar PV in the middle east | UAE |
| **15** | A technical specialist for hydrogen and green chemicals at an MNC | UAE |
| **16** | A young professional in the hydrogen business development | UAE |

| | | |
|---|---|---|
| **17** | A professional focussed on investing and economic assessment on renewable energy and hydrogen projects | UAE |
| **18** | A green energy enthusiast and working as a pipeline engineer in UAE | UAE |
| **19** | An investor in green energy focussed on the middle east | UAE |
| **20** | A market strategist focussed on introduction of hydrogen mobility in the middle east countries | UAE |
| **21** | A project originator for renewable energy in UAE | UAE |
| **22** | A consultant providing renewable energy solutions to energy-intensive industries | UAE |