Beyond the technology: Public Perception of Ammonia Energy Technologies

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This thesis is submitted to Cardiff University in partial fulfilment of the requirements for the degree of Doctor of Philosophy

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PREFACE

Some of the results presented in chapters 6 and 7 are also reported in the following publications:

The findings from the focus groups (Chapter 6), are also available at:

Valera-Medina, Agustin, & Banares-Alcantara, R. (2021). Techno-Economic Challenges of Green Ammonia as an Energy Vector. Techno-Economic Challenges of Green Ammonia as an Energy Vector. *Elsevier*. https://doi.org/10.1016/c2019-0-01417-3

The findings from the Survey (Chapter 7), are also available at:

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"Todo descubrimiento es un deseo, y todo deseo, una necesidad. Inventamos lo que descubrimos; descubrimos lo que imaginamos. Nuestra recompensa es el asombro"

- Carlos Fuentes

THESIS SUMMARY

Ammonia is gaining popularity around the world due to its advantages as an energy vector over other zero-carbon fuels. However, little is known about public attitudes and concerns about the technology, one of the factors that will determine its successful implementation. This research provides the first empirical 'public perception' study about ammonia as an energy vector and for energy storage in the context of climate change. Through a mixed-method approach (using both qualitative and quantitative methods) this research examined the differences between experts' and laypeople's perceptions of green ammonia technologies in two different contexts (Mexico and UK). The results are discussed in relation to the literature examining several factors involved in this process. Positive responses towards the technology were found, nevertheless these are highly dependent on several factors, such as framing, the perception of risks and benefits, trust, context among others. This research provides insights into ammonia public perceptions with implications for future risk communication about its use. It concludes by highlighting the importance of involving the public at early stages of the development of the technology. Mainly, with upstream technologies, like ammonia, where its effectiveness, cost and risks are uncertain, public perception studies will point out ethical and value issues people consider important. The next step of innovation is not only to consider technical aspects but to recognise the importance of a joint effort between key players and formulate an ethics of care for the future, where a comprehensive vision is in line with ethical reasoning, taking into account both public and stakeholders.

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LIST OF ABBREVIATIONS

CFE	Comisón Federal de Electricidad (Federal Electricity Commission)
Conacyt	Consejo Nacional de Ciencia y Tecnología (National Council of Science and Technology)
CONAGUA	Consejo Nacional del Agua (National Water Commision)
HB	Haber Bosch process
EPA	Environmental Protection Agency
EU	European Union
FGs	Focus Groups
GHG	Greenhouse Gas
IEA	International Energy Agency
IMO	International Maritime Organization
LPG	Liquid Petroleum Gas
PEMEX	Petroleos Mexicanos (Mexican Petroleum)
UK	United Kingdom
US	United States
RIF	Responsible Innovation Framework

CHEMICAL COMPOUNDS

Ammonia (NH_3)

Carbon Dioxide (CO_2)

Hydrogen (H_2)

Methane (NH_4)

Nitrate Oxides (NO_X)

Nitrogen (N_2)

Chapter 1. INTRODUCTION

Energy consumption has grown exponentially across the world over the past years, along with society's dependency on fossil fuels (Rodriguez, 2020). According to the US Energy Information Administration (EIA), energy use worldwide will continue to grow for at least another three decades due to economic growth (EIA, 2019). The EIA estimates that the total energy consumption will increase 15% for OECD countries and nearly 70% for non-OECD countries between 2018 and 2050.

Due to the rapid increase in demand for energy, governments, industries, academics and other experts are trying to find a way to ensure supply while at the same time continuing to reduce greenhouse gas (GHG) emissions. Efforts between countries have been made and settlements such as the Paris Agreement are also in place to achieve a long-term goal – to limit global warming to below 2º Celsius (United Nations Climate Change, 2018).

One way to accomplish this objective is to identify technologies that provide reliable, affordable and clean energy. Nevertheless, developing these technologies is a challenging task. To shift from oil-based fuel to energy produced from renewables is however an aim most countries are focused on (IEA, 2021). According to (Goodall, 2016), transitions from one fuel to another could take half a century or more; the move from wood to coal took this long and the shift from coal to oil and gas took about the same time.

Currently, liquid fuels, especially petroleum based, are the largest energy source around the world (Yildiz, 2018). They present several advantages over any other energy systems such as low cost, high reliability, and efficiency; these characteristics are required in any fuel to be useful for a wide range of activities and purposes. Nevertheless, the path for renewable energies is getting clearer and growing (IRENA, 2018). Solar, wind, hydro and marine energy, among other green technologies, will become cheaper and more efficient in the next decades, leading to a new era in energy generation (British Petroleum, 2020).

Unquestionably, the impact of the Paris Agreement on the energy sector is significant. According to the United Nations Climate Change to achieve long-term goals of the agreement, "renewables in the world's primary energy supply must be raised from the current 15% to 65% by 2050" (UNFCCC, 2018, para.2). Therefore, it is essential to transition away from fossil fuels to low-carbon solutions, as carbon dioxide (CO^2) emissions account for two-thirds of all GHGs (International Energy Agency (IEA), 2019). This energy transition will only be possible through technological innovation, notably by finding zero carbon energy alternatives and new ways to store excess energy from renewables.

Ambitions of renewable energy targets are consistently raised in many countries as part of the effort to achieve climate neutrality by 2050, with many regions and countries having ambitious carbon emission reduction targets. For instance, the European Union (EU) has adjusted its 2030 target for a net reduction in GHG emissions from 27% that was set back in 2014, to 55%, in July 2021 (European Commission, 2020a). The United Kingdom (UK) has already reduced emissions by 42% and has one of the most ambitious targets in the world. In 2008 the UK passed the *Climate Change Act* which set out emission reduction targets that must be complied with legally. This act was the first legally binding climate change mitigation target set by a country (Grantham Research Institute, 2020). Consequently, in 2019 a more ambitions target was set: to achieve net zero by 2050. The UK was the first major economy to commit to a net zero target (Shepheard, 2020). In 2021, the UK announced the new "Net Zero Strategy" to achieve this goal by primarily using electrification, hydrogen and technological innovation including renewable and nuclear energy (Carbon Brief, 2021).

As part of this strategy, the UK also revealed the first-ever Hydrogen Strategy focused on cleaner energy sources. The government will provide £105 million funding to support polluting industries to significantly reduce their emissions and achieve the goal of net zero by 2050. The strategy aims to utilise low-carbon hydrogen obtained through wind farms across the UK, allowing the reduction of emissions by 78% by 2035.

This is not an easy task; finding a zero-carbon fuel that also remains economically beneficial and reliable, is currently a challenge. For the purpose of this research, we will focus on the concept of green ammonia as a carbon-free energy vector and long-term energy storage option. (*Chapter* 2 will discuss in more detail the current role of ammonia and green ammonia production).

Renewable energy presents countless benefits for the environment, however due to their intermittent and unpredictable nature, energy storage needs to be used to ensure that the required power load is met at all times (Larcher & Tarascon, 2018). When referring to storage methods suitable to be employed with renewable energy, there are many possible options available in the market, but the most popular and technologically mature option are batteries. However, these devices currently represent low-efficiency and high costs for long-term storage (Spector, 2020).

Nowadays, few fuels exist that do not produce CO_2 emissions (i.e. hydrazine, hydrogen sulphide, ammonium nitrate, ammonia etc.). Research indicates that amongst these, hydrogen and ammonia are the simplest and most promising (IRENA, 2019) due to their physical properties such as energy density and efficiency. They also benefit from existing knowledge in the fertiliser industry on how to use these compounds.

Hydrogen is a popular option as a zero-carbon fuel to help reduce GHG emissions. However, due to its chemical composition, shipment across long distances and storage for long periods present a lot of challenges. Therefore, another way to use hydrogen is through ammonia, a chemical that contains hydrogen (Tullo, 2021). Ammonia is the focus of this thesis.

Ammonia (NH_3) is a chemical well known all around the world mainly as a fertiliser, and it is currently the second most produced chemical worldwide after sulphuric acid (R. Service, 2018). As a fuel and storage method, it relies on its high hydrogen content, and it is perceived as one of the key players for a transition to a decarbonisation society (Wilkinson, 2017) (The Royal Society, 2020) (Norton Rose Fulbright, 2021). We will focus on the concept of green ammonia; it is called "green" because it does not contain carbon and it is powered by green technologies (Lipman, 2007).

With the current applications of ammonia as a fertiliser and chemical compound, existing knowledge and infrastructure, along with the attractive characteristics as a zero-carbon fuel, recognition for the possible use of NH_3 is increasing and industries are investing in this chemical as an energy vector and storage method.

However, the successful adoption of a new technology such as ammonia is not only dependent on its physical/technical properties but also on societal factors, including public acceptability (IRENA, 2020). Little is known about public attitudes and concerns around this technology; one of the factors that could support its successful implementation (*Chapter* 3 provides an overview of the literature on public perception of low-carbon energy systems).

Understanding public acceptability of a technology is complex and dependent on many psychological, social and contextual factors. It is true that developing a new technology often brings several benefits for the public, especially when referring to zero-carbon technologies; yet, as with any project involving the public, it is always a challenge to understand peoples' process of acceptance. Numerous factors start playing an important role, such as affect, cultural backgrounds, associations, place attachment, just to mention a few (Breakwell, 2014).

Researchers have been trying to analyse these complex interactions between the general/local public and the development of new energy technologies (Kim et al., 2020). In the case of hydrogenated vectors, there are several studies trying to understand people's attitudes towards these new fuels (Ricci et al., 2008a), recognizing the significance of understanding the social contexts and processes relevant for the deployment of new hydrogen systems (Maack & Skulason, 2006).

However, this is not the case of ammonia-based technologies. Currently, there are no formal studies analysing public perception of ammonia as a potential energy vector or as a storage medium. Therefore, this research aims to provide the first empirical 'public perception' study about ammonia as an energy vector and for energy storage in the context of climate change. The research conducted as part of this thesis will provide initial explorations into public perceptions around this subject, enabling future stakeholders to consider the findings throughout the development of new technologies fuelled by NH_3.

1.1. Objectives and general research strategy

The main objectives of this research are to **(1) understand people's perceptions and concerns about ammonia as an energy vector and for energy storage in the context of climate change**. In particular, the project examines people's perceptions of the technology and its uses, its governance and societal implications. **(2) Explore how key public perceptions of green ammonia differ across two different socio-cultural contexts (Mexico and the UK)** and (3) **compare key risk and benefit perceptions between experts and the public**.

These broader objectives are supplemented by more specific and detailed aims for each research phase (see below). Rationales for key aspects of the chosen research approach are briefly described in the following sections and expanded upon in the relevant chapters. This includes why the research focuses on both experts and public perceptions, why data collection was conducted in both Mexico and the UK, and why a pragmatic mixed-method approach was considered most appropriate for addressing the objectives and aims of the research.

The research is divided in two main phases (see *Fig*. 1 below). The first focuses on experts and their perceptions on ammonia technologies (Phase1), and the second on the general public (Phase 2).

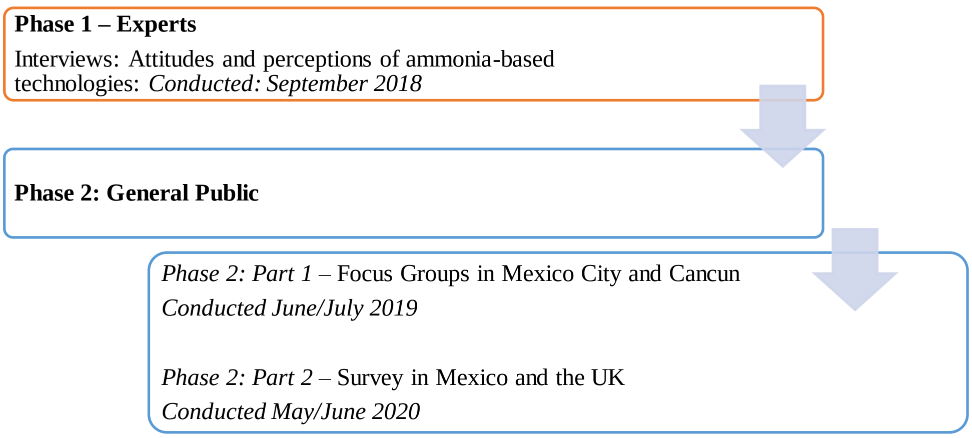

Figure 1.1. Thesis research layout

As Figure 1.1 illustrates, a mixed-method, or multi-method approach was selected and considered appropriate to answer the research aims (see section 1.1.1). *Chapter 4* discusses each of the used methods, providing a detailed rationale for their integration in this research.

1.1.1 Specific research aims

Phase 1 (P.1) involved interviews with experts in ammonia. The aims for this phase were:

1. To gain a better understanding of why ammonia energy technologies are being developed and how these are envisaged to be part of a future energy system. Findings from this phase will also be used to create materials for presentation to public participants in phase 2 of the research.
2. To understand key risk and benefit perceptions of green ammonia among those involved in its development (for comparison with public perceptions) and compare these to risk and benefit perceptions of the lay public (phase 2).
3. To understand whether and how experts involved in the development of green ammonia perceive public perceptions to be an important aspect of technology development.

Phase 2: Part 1 (P2.1) consisted of FGs with the general public in Mexico. The specific research aims for this phase were:

1. To explore people's initial associations and responses to ammonia and its possible use as an energy fuel and storage technology in Mexico.
2. To examine people's risk and benefit perceptions of ammonia as an energy vector in the context of climate change. To explore other relevant perceptions such as views on governance of ammonia as an emerging technology.
3. To explore public perceptions and understandings of climate change and how different energy sources may contribute to carbon emissions in Mexico.

The third aim of this phase was added because very little research exists that explores public perceptions of climate change in Mexico. Most studies of such nature were conducted in Europe or United States (US).

Findings from this research phase were used to compare public and expert perceptions and to build the questionnaire for the survey in the next phase.

Phase 2: Part 2 (P2.2) involved online quantitative surveys with the general public in Mexico and the UK. The specific aims of this research phase were:

1. To examine public responses and perceptions and understanding of ammonia in a larger, more representative sample.
2. To compare key perceptions across Mexico and the UK to gain a better understanding how the national and socio-cultural context may shape views.

3. To explore how socio-demographic factors and climate change perceptions relate to public support for green ammonia technologies

1.2. Experts and public perceptions

Public perceptions of ammonia in the context of climate change are the main focus of this thesis as outlined in the objectives and specific research aims. This is an exploratory first study in this area and aims to provide a basis for future research and development of the technology.

Nonetheless it was also considered important to examine expert perceptions to better understand why green ammonia is being developed, what challenges exist and what role public perceptions may play in its development. It should be acknowledged that some previous risk perception research on topics such as climate change and other technologies employed a 'mental models approach' which carefully maps public and expert perceptions and understandings of a topic to later compare these and identify differences (Bostrom, 1997) (P. Cox et al., 2003). However, this thesis does not employ a mental model's approach because the main aims were more exploratory in nature. The discussion, nonetheless, provides an initial analysis comparing lay and expert perceptions of green ammonia.

1.3. Study location: Mexico and the United Kingdom

The public perception research (phase 2) was primarily conducted in Mexico, with additional data collection in the UK for the quantitative survey (phase 2.2).

1.3.1. Mexico

Mexico was chosen due to the (1) **well-established knowledge and infrastructure around ammonia** and because (2) **the research was funded by the Mexican government (National Council of Science and Technology)**.

Mexico is a global producer and exporter of agricultural products, it is the main vegetable producing country in Latin America (Statista, 2016) and controls 31% of the total exports worldwide of citrus and melons (Canales et al., 2020). As a consequence of Mexico's biodiversity, agriculture is a fundamental part of the country's economy with a yearly growing production value (Statista, 2021).

Therefore, the country is a large producer and consumer of fertilisers (ammonium nitrate[1]), an industry that has been growing exponentially in Mexico for the past five years (Atlas Mundial de Datos, 2018). This translates to existing infrastructure for the transportation and storage of ammonia gas, as well as

[1] Ammonium nitrate, (NH_4NO_3), is a salt of ammonia and nitric acid, used widely in fertilizers and explosives.

local knowledge on how to handle ammonia. Currently, the national oil company, Mexican Petroleum (PEMEX), owns four ammonia plants located in in the Gulf of Mexico, being the only producer of ammonia in the country, producing 1.6 million tonnes of ammonia per year (PEMEX,2015.

Additionally, it has an ammonia distribution system that goes from Veracruz to Oaxaca by land, and to the north of Mexico by sea (see *Fig* 1.2). The current ammonia is produced by reforming natural gas and stored in tanks located in the north and south of the country.

Figure 1.2. Ammonia distribution map (PEMEX, 2017)

Due to the high revenues in agriculture and its dependency on ammonia as a fertiliser, we chose Mexico as one of the countries to carry out this research and analyse acceptance at a socio-political level.

Additionally, a second motive for carrying out the research in Mexico is that this research has been funded by the National Council of Science and Technology in Mexico (abbreviated CONACYT). This entity is in charge of the promotion of scientific and technological activities, setting government policies for these matters and granting scholarships for postgraduate studies. One of the requirements of the grant is to involve the country in every study. Furthermore, very little research into public perceptions of climate change and energy related topics exists in Mexico so this study also contributes to knowledge production in this area.

Data collection in this country was carried out using focus groups (*P2.1*) and a survey (*P2.2*).

P2.1 – Four focus groups (FGs) took place in Mexico, three in Mexico City and one in Cancun. The reason the UK was not selected for this specific part of the *research* was for two reasons. First and most importantly, the PhD project lacked financial resources which restricted the possibility to obtain economic compensation for participants in two countries. Second, as a consequence of the lack of resources there was a need to choose only one country to carry out the FGs. Mexico was chosen due to the lack of research about public perception of energy systems and climate change; this represents an opportunity to contribute to a field that is not yet fully developed in this country, unlike in the UK.

Mexico City and Cancun were chosen to collect data from diverse geographic locations and due to the researcher's familiarity with both cities. Detailed information about the location and recruitment for P2.1 can be found in *Chapter 6*.

P2.2 – The survey was distributed online across Mexico to understand perceptions of green ammonia in the context of climate change for a larger and more diverse sample. *Chapter 4* describes the socio-political context of the country while data collection was taking place.

1.3.2. United Kingdom

The UK was chosen as a second country in this study **due to the potential of green ammonia as a storage method for excess energy from renewables**.

As mentioned previously, the UK is a world leader in renewable energy. In 2019, the British Prime Minister Boris Johnson, announced an investment of £134 million across the green sector to develop new technologies and secure new jobs, with the objective to become the world leader in clean wind energy (Costa Figueira, 2020), (BEIS & Innovate UK, 2020).

In order to achieve this goal, energy storage is a fundamental aspect. One of the main drawbacks of renewable energies is the intermittency in the electricity they produce, while the grid's capacity to store excess energy from green technologies is not enough to meet current demand. Therefore, a successful deployment of renewable energy is highly dependent on effective long-term storage methods. If the aim of the UK is to be the leader of clean wind energy, energy storage for both, short and long periods, is needed (European Commission, 2020b).

Technological innovation for energy storage keeps improving every year. There are many possible options for energy storage, for example pumped hydro storage and batteries. Pumped hydro storage is mostly use for long-term storage, however this this technology relies on geographical conditions (e.g. mountains and water) (International Renewable Energy Agency, 2019). On the other hand, when referring to on-site storage (taking place or situated at a particular place or site) the most popular and technologically matured option are batteries. Nevertheless, these devices currently represent low-efficiency and high costs for long-term storage (Spector, 2020). Hence, experts have been looking at other options for energy storage and suggested the use of chemicals. This type of chemical storage is based on substances such as hydrogen, ammonia or methane that can be used to store energy for longer periods (Valera-Medina & Banares-Alcantara, 2021).

Ammonia has been proven to be a potential chemical for long-term energy storage (see *Chapter* 2). Currently, there is a project already under development in Orkney Islands, Scotland. The site will store excess energy from wind turbines as liquid ammonia and use it for transport and a local heat network (HIT project, 2021). With the increasing interest of ammonia as an energy vector and storage medium, it is essential to start considering public acceptance. This is the reason why the UK was chosen as a second country for this first formal 'public perception' study of green ammonia.

Data collection in this country was carried out using an online survey distributed across the UK to gain a diverse and large sample.

1.4. Thesis outlook

Chapter 2 – From ammonia to green ammonia

This chapter discusses technological aspects of ammonia as an energy vector and for long-term energy storage. First, it presents the current production of ammonia and the potential of utilising this chemical as a carbon-free fuel, highlighting the advantages of this gas over other zero-carbon fuels and storage options. Second, it introduces the concept of green ammonia, displaying the benefits if used for power generation or energy storage. This section presents current projects and investment around the world.

The chapter also describes challenges green ammonia technologies face and introduces public perception of green ammonia as a topic that is not yet explored and that will determine the successful implementation of this technology. Moreover, it highlights the importance of this type of studies in the energy sector and determining the importance of carrying out research such as the one presented in this thesis.

Chapter 3 – Literature Review

This chapter presents a review of the relevant public perception literature. This section is divided into four main sections with various thematic subsections in between, providing an overview of the body of knowledge relevant for understanding public perceptions of green ammonia. This includes literature on public perceptions of low-carbon technologies, emerging technologies and climate change. Relevant concepts to the present research and in line with the study's questions.

This literature review begins by introducing and defining key concepts relevant to explore public perceptions of green ammonia as an emerging technology such as beliefs, attitudes, public acceptance and acceptability. Followed by an in-depth discussion of public acceptance of low-carbon energy sources.

The second section briefly focuses specifically on public perception of emerging technologies. Providing further literature on different aspects that should be considered when analysing these types of technologies: Preference construction, pseudo-attitudes, information -provision and framing are examined in this section.

The third section will briefly expand on the topic of risk perception, analysing the role of experts and laypeople perceptions within the development of low-carbon energy projects, hydrogenated and ammonia systems.

The fourth section of this chapter presents current research on climate change (CC) perceptions discussing the results of international surveys about this topic. This section also discusses the importance of analysing CC knowledge, causes and beliefs as relevant to the objectives. It concludes with the theoretical framework connecting all the concepts to the objectives.

It is important to highlight that, while there is extensive research on climate change and public perception of upcoming energy technologies, so far, there has been no detailed assessment of people's understanding of ammonia-based systems. Instead, related topics have been analysed in more detail such as hydrogen and alternative energy systems. For this reason, all of the topics presented in this thesis are relevant to get a first idea about how people will react to the concept of 'ammonia energy systems'.

Chapter 4 – General Methodology

This chapter provides a general rationale of the study, focusing on methodological aspects. It describes each of the approaches utilised (qualitative and quantitative) and explains how these were employed to collect data during the research. Additionally, the importance of applying a mixed methodology approach for analysing public perception of emerging technologies is presented.

Following the section of methodological approaches, the chapter included a reflection on researcher bias and positionality regarding data collection and analysis.

It concludes by introducing the concept of cross-national research and presenting the socio-political context in Mexico and the UK. This chapter provides a general methodological framework for the research. Detailed methodology descriptions of each phase are included in subsequent empirical chapters (*Chapters* 5, 6 and 7).

Chapter 5 – Phase 1: Experts

This chapter is divided in two sections: methods and results. All the results' chapters (chapter 5,6 and 7) follow this same structure where first an explanation about the methods utilised to collect data are presented, followed by a detail analysis and presentation of the findings.

The chapter begins by introducing the methods used to collect and analyse data for the purpose of phase 1 (interviews). A rationale of phase 1 is presented at the beginning of the chapter, along with the description of the study and an explanation about how the data was analysed.

In the second section, the chapter starts by briefly introducing the structure of the results. It is divided into four subsections, where the answers for each set of questions are analysed following the interview protocol structure. After understanding the reasons why experts are working with ammonia-based systems, the research examines perceptions of advantages and disadvantages of the technology, as well as concerns, benefits and risks. This is followed by the perceived role of laypeople, perception of future costs and points of view about using ammonia to store excess energy from renewables. Lastly, the chapter presents the conclusion and briefly discusses key limitations.

Chapter 6 – Phase 2. Part 1: Focus Groups

This chapter is divided in two sections: methods and results. The chapter first describes the methods used to collect and analyse data for the purpose of phase 2, part 1. It begins by presenting a rationale of this phase and justifying the methodology. This is followed by a description of the questionnaire and structure of the FGs. It introduces the research strategy and how the sample was selected. Consequently, an overview of each of the FGs is given to provide context for the analysis in following sections.

For the second section, results are displayed in the same order as the interview protocol, divided into six main topics: (1) first associations (2) climate change (3) fuels (4) green ammonia (5) ammonia in Mexico and (6) trust. Each of the topics is analysed and described in detail providing an overview of perceptions in each FG. To conclude, we include a summary and discussion of the findings and limitations to consider in future research.

Chapter 7 – Phase 2. Part 2: Survey

This chapter is divided in two main sections: methodology and the results. It begins by providing all the necessary information about the methods used to collect and analyse data for the purpose of the second phase: part two. It describes the research strategy, participants and recruitment procedures, and consequently presents a comprehensive justification of the questionnaire structure and the process of data analysis.

The second section describes and analyses the results obtained from the survey distributed in Mexico and the UK between May 20th and June 18th 2020. It begins with an analysis of the profile of participants (Q.1- 6) in both countries and comparing it to national statistics. This is followed by a short description of first associations with the word *ammonia* (Q.7). Following this, climate change perceptions (Q.8-13) and climate change knowledge (Q.16-19) are analysed. The chapter goes on to analyse respondents' initial responses to the idea of green ammonia (Q.19-21), followed by perceptions of risks and benefits (Q.22-26) and acceptance of ammonia projects in their country (Q.27-29).

It concludes by examine to what extent demographics and climate change (CC) risk perception predict support for green ammonia technologies. Additionally, the chapter provides conclusions and limitations.

Chapter 8 – Further Discussion and Conclusions

This final chapter summarizes the findings obtained throughout the research structured around the three main objectives of this thesis.

First, it combines all the results obtained from the two research phases with the general public (FGs and survey) to gain a general idea of the perception of laypeople regarding green ammonia. Later, this first section provides a detailed analysis of general results linked to research presented in the literature review. Second, the chapter discusses how the sociocultural context shaped the perceptions of the technology in the UK and Mexico. Third, key risk and benefits perceptions of experts and general public are compared. These three sections of analysis provide an examination based on the theoretical framework presented on the literature review (*Chapter 3*).

Consequently, the chapter presents general limitations and provides detailed suggestions for further research. It concludes with specific recommendations for stakeholders and developers of green ammonia. General conclusions are also presented at the end of the chapter.

Chapter 2. FROM AMMONIA TO GREEN AMMONIA

2.1. Introduction

This chapter discusses the role of ammonia as an energy vector and for long-term energy storage. First, it presents the current production of ammonia and the potential of utilising this chemical as a carbon-free fuel, highlighting the advantages of this gas over other zero-carbon fuels and storage options. Second, it introduces the concept of green ammonia, clarifying the benefits if used for power generation or energy storage. This section presents current projects and investment around the world.

Additionally, this chapter briefly explores challenges for green ammonia development and deployment. Public perceptions and acceptance of green ammonia is introduced as an important aspect for technology development and a potential challenge in the future.

2.2. An overview of ammonia

A transition to a period where renewables play a critical role will only be possible through technological innovation, particularly by finding zero-carbon alternatives and new ways to store excess energy from renewables for longer periods of time.

Currently, only a few fuels exist with no carbon (i.e., hydrazine, hydrogen sulphide, ammonium nitrate, ammonia etc.) that can also be used for energy storage. Research indicates that amongst these, hydrogen and ammonia are the simplest and most promising (IRENA, 2019).

Hydrogen is an excellent zero-carbon fuel to help reduce GHG emissions. It does not produce carbon as a by-product during operation and it can be obtained from water (US Department of Energy, 2017). However, due to its chemical composition, shipment for long distances and storage for long periods present challenges. Therefore, another way to use hydrogen is through ammonia (Tullo, 2021).

Ammonia presents significant advantages over hydrogen. It holds all the benefits of hydrogen while also having better physical characteristics, lower cost per unit of stored energy, higher volumetric energy density, easier production, handling and distribution, and better commercial viability (Valera-Medina et al., 2018).

The current research is focused on the properties of ammonia for power generation and energy storage. As a fuel, ammonia relies on its high hydrogen content - this characteristic allows it to be used at any time as a fuel, for electricity generation or energy storage while at the same time being used as a chemical for fertilisers and other products.

Ammonia is a chemical well known all around the world due to its uses mainly as a fertiliser. Currently is the second most produced chemical worldwide just after sulphuric acid. Companies around the world produce approximately $60 billion worth of ammonia every year (R. Service, 2018).

The most popular method to produce ammonia is by a process called Haber-Bosh (HB) where nitrogen (N_2) and hydrogen (H_2) are combined at high temperatures to produce ammonia (NH_3) (Giddey et al., 2013).

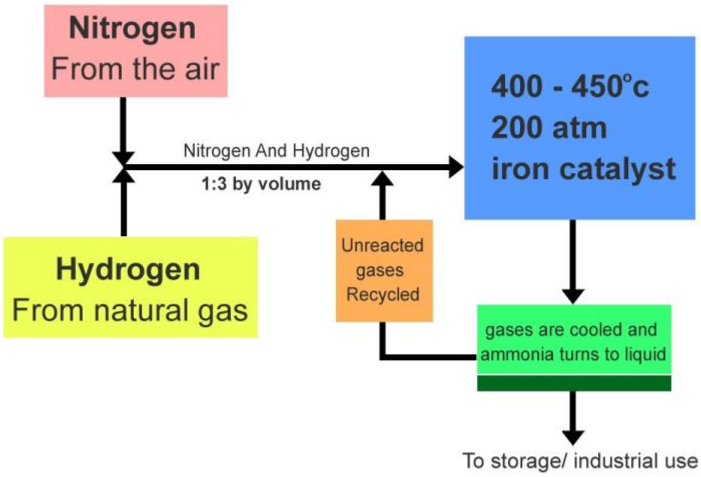

Figure 2.1. Flow diagram of the Heber-Bosh process (Piyush Patel, 2020)

In this process (see Fig. 2.1) the nitrogen is obtained from the air and the hydrogen from natural gas. Nowadays, this method is the most used around the world due to the low cost per unit and efficiency. However, it is extremely energy intensive due to the high temperatures needed to split the molecules and is also carbon intensive due to the natural gas utilised to obtain hydrogen, releasing carbon dioxide (CO_2) in the process. Around 450 million tons of nitrogen-based fertilisers are manufactured every year using the HB process (Piyush Patel, 2020).

2.2.1 Current ammonia demand and production

Approximately fourth fifths of all ammonia production in the world is used to produce nitrogenous fertilisers (e.g. urea and ammonia nitrate) (see Figure 2.2) which contributes to global food production (IRENA & AEA, 2022) the remaining left is used in the chemical industry for pharmaceuticals, plastics, textiles, explosives, among others. In 2020 ammonia global ammonia production reached 243Mt from which 90% was consumed on-site as feedstock for downstream processes, and the rest 18-20 Mt was transported annually by ship (IRENA & AEA, 2022). Currently, China is the largest ammonia producer in the world followed by Russia and the U.S (Wood, 2021). It is estimated that companies around the world produce approximately $60 billion worth of ammonia every year (Service, F.R, 2018).

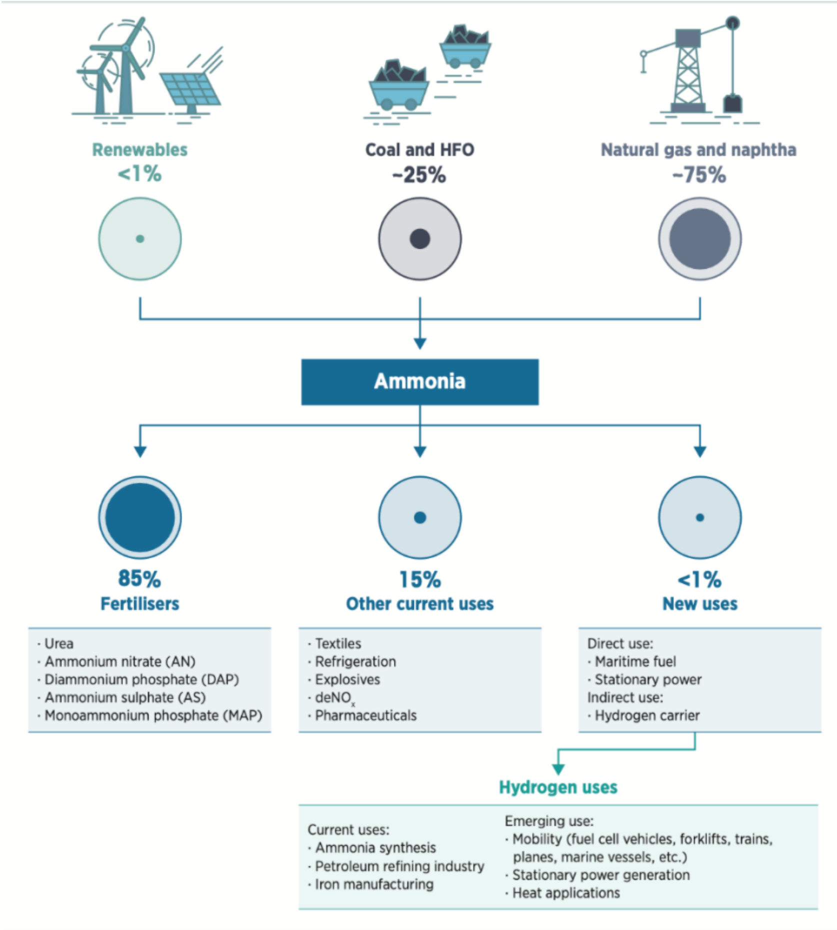

Figure 2.2. Production and uses of ammonia (IRENA & AEA, 2022).

Regarding global ammonia demand, in 2020 it was estimated to be 183Mt (IRENA & AEA, 2022). As we can observe in Figure 2.3, ammonia demand has been increasing exponentially every year, according to numbers from the Ammonia to Green Hydrogen Project, the growth over the years has been at an average rate of approximately two percent (Ecuity et al., 2020) . This numbers are expected to continue increasing due to population growth and increase in food production (Wood, 2021).

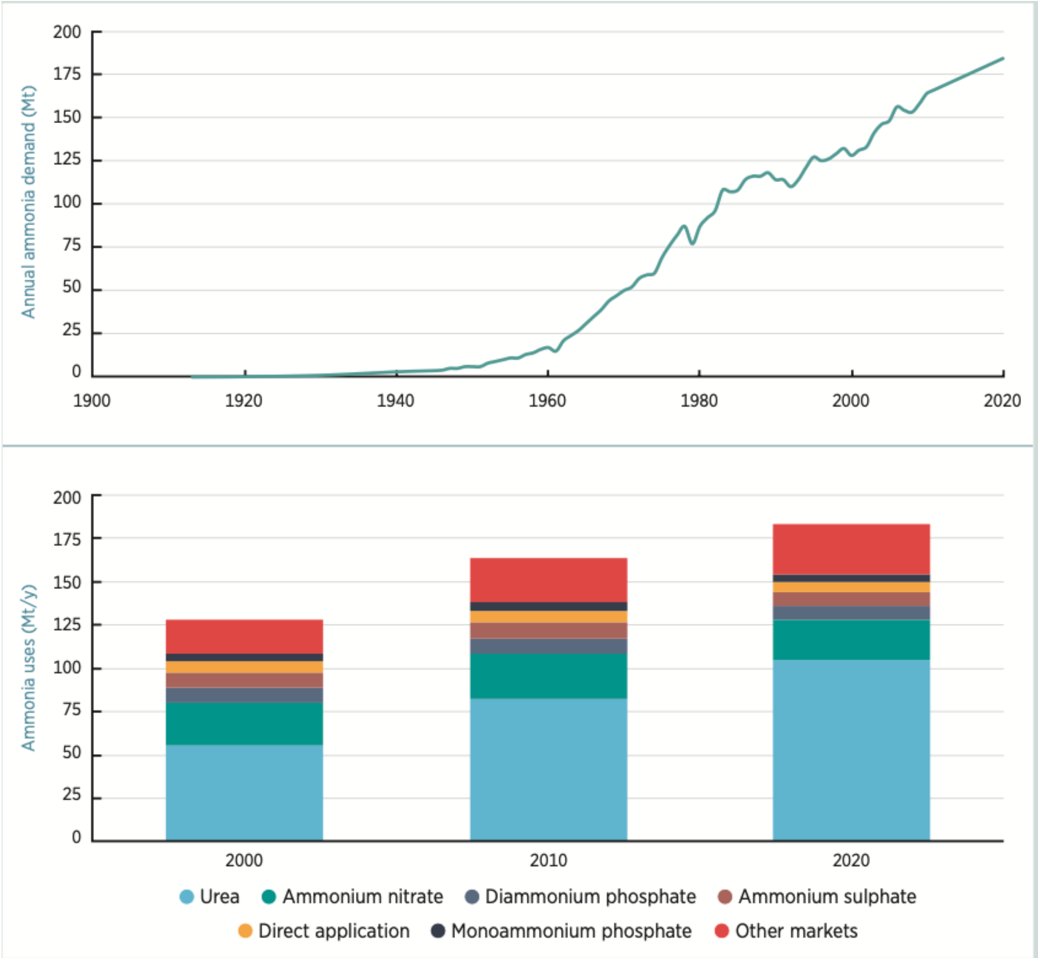

Figure 2.3. Global ammonia demand[2] (IRENA & AEA, 2022).

2.3. Green Ammonia

Another way to produce ammonia is through an electrochemical process. In this process nitrogen is still obtained from the air, however instead of using natural gas to obtain hydrogen, the process uses water (H_2O) (see Figure 2.4). Additionally, the electricity needed to split the molecules is obtained from renewable energies, avoiding the use of carbon fuels throughout the process. The ammonia obtained by this process is called "green ammonia" (Lipman, 2007) because it does not contain carbon and it is powered by green technologies. Nevertheless, less than 1% worldwide of the ammonia is produced this way currently (IRENA & AEA, 2022) (Morgan, 2013).

[2] Direct application refers to the use of ammonia as fertiliser. Other markets include the textile industry, the explosives and mining industry, pharmaceuticals production, refrigeration, plastics manufacturing, waste treatment and air treatment, such as NOx abatement.

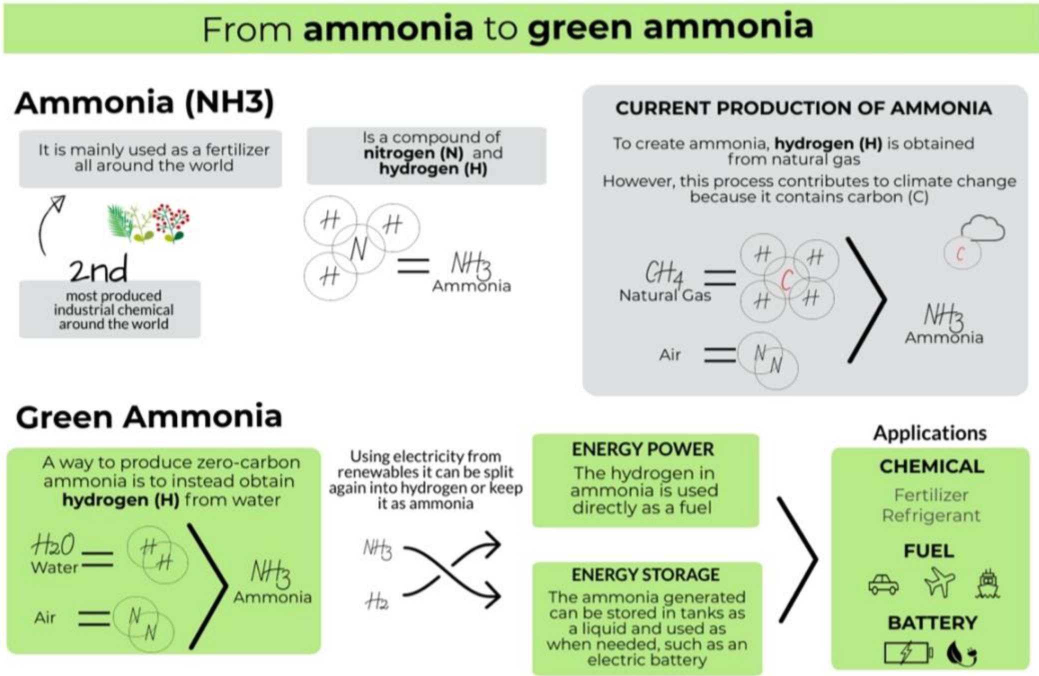

Figure 2.4. Infographic from ammonia to green ammonia.

2.3.1 Green Ammonia for Power Generation and Energy Storage

As mentioned previously, ammonia contains a large amount of hydrogen; this characteristic allows it to be used as a fuel, for electricity generation or energy storage (see Fig. 2.5). For the purpose of this research, how ammonia may be used in power generation and energy storage is of particular relevance.

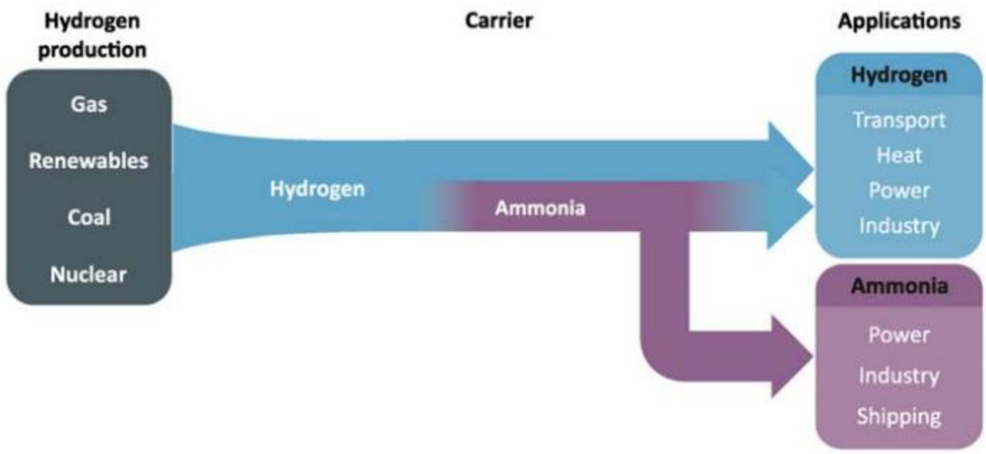

Figure 2.5 Applications of hydrogen. (Birol F. Hydrogen: accelerating & expanding deployment. Hydrogen energy ministerial, Tokyo. IEA; October 23, 2018. Available from: https://www.nedo.go.jp/content/ 100885441.pdf. (Accessed 15 November 2019). All Rights Reserved). Retrieved from: (Valera-Medina & Banares-Alcantara, 2021)

2.3.1.1 Power Generation

Ammonia can be used as a fuel and energy vector in engines, fuel cells and turbines. It can also be used as a hydrogen carrier, which means storing hydrogen as ammonia and then splitting it back to hydrogen when needed. Due to its properties, ammonia can be utilised to store hydrogen as long as required and make it available when and where it is needed (Catillaz & Goldmeer, 2021).

Currently the use of ammonia as a fuel is gaining popularity around the world. The biggest green ammonia project at the moment is funded by the Australian Renewable Energy Agency who, in May 2021, awarded an AU$42.5 Million[3] grant to build a renewable hydrogen plant to produce green ammonia. This project is scheduled to be completed by 2023 and aims to export green hydrogen to the Asian region (Paul, 2021). In line with this investment, Japan has successfully fuelled gas turbines with ammonia and has declared to use 3 million tonnes of ammonia each year by 2030 to cut their carbon emissions (Financial Times, 2020).

Another industry highly interested on green ammonia as a fuel is the maritime industry. The reason for this is because on top of its zero-carbon properties, this chemical can be used in fuel cells and internal combustion engines and does not need to be stored in high-pressure tanks (like in the case of hydrogen). At the same time ammonia has 10 times the energy density of a lithium-ion battery. In 2018, the International Maritime Organization (IMO) set a long-term target to decrease GHG emissions by 50% from international shipping by 2050 (Abbasov, 2018). It has been suggested that one way to accomplish this goal could be to replace current maritime fuels with ammonia. Different companies have already started to explore this possibility by designing new ammonia-based engines (Maria Gallucci, 2021) (Safetyforsea, 2020).

2.3.1.2 Energy Storage

As an energy storage method, ammonia is considered to be a promising option (S. Evans, 2020) to address the challenge of large-scale, long-term, easy to transport energy storage in a decarbonised energy system future (The Oxford Institute for Energy Studies, 2020), see Figure 2.6. Currently renewable energy present countless benefits for the environment, however due to their intermittent and unpredictable nature, energy storage needs to be used to ensure that the required power load is met at all times.

[3] Australian dollars

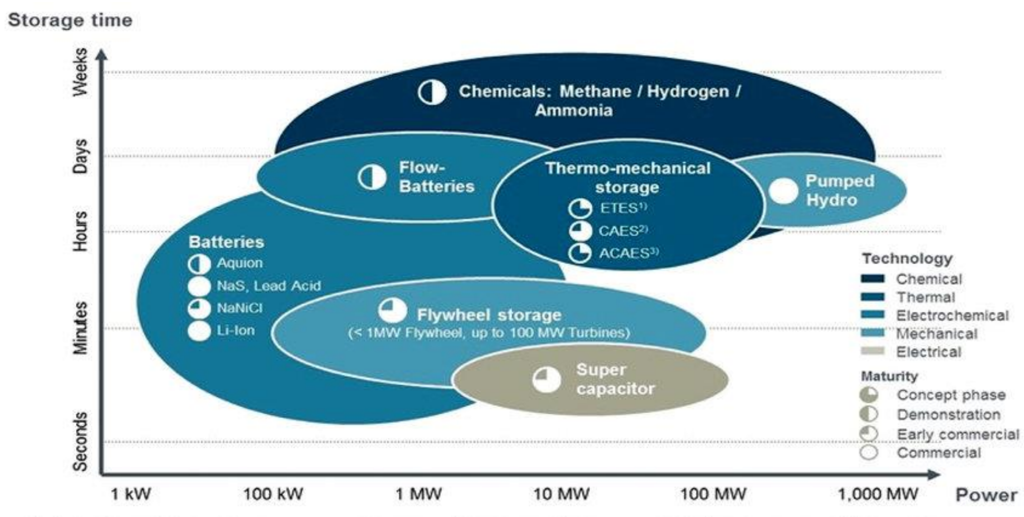

Figure 2.6. Comparison between different storage technologies.
Courtesy of Dr Ian Wilkinson, Siemens. Retrieved from: (Valera-Medina et al., 2018).

There are four main types of energy storage technologies: electrical, electrochemical, mechanical, and chemical. Depending on the required scale and storage duration needed, each will represent different advantages. Table 2.1 provides a comparison between different carbon-free storage options.

Table 2.1. Energy storage technologies comparison
(Information retrieved from the report: Ammonia as a storage solution for future decarbonized energy systems (The Oxford Institute for Energy Studies, 2020).)

Type	Appliances	Round trip efficiency (%)	Energy density (Wh/l)[4]	Storage duration	Advantages	Disadvantages
Electrical	Superconductors	90-94	2-10	Seconds, minutes, hours, days	Easy to store and transport. High efficiency	Low energy density, storage capacity, storage time High self-discharge rate. High costs per installed density
	Supercapacitors	80-90	0.5-10			
Electrochemical	Vanadium Redox flow	60-70	20-70	Hours Days	Easy to store. Potentially transportable. Medium efficiency	High costs. Medium storage time. Relatively high self-discharge
	Lead-acid	70-80	50-100	Hours Days	Low self-discharge. Low power installation costs. Transportable	High costs. Medium storage time. Leak-prone

[4] Wh/l: Watt-hours per litre. Energy density implies how much energy a battery can hold.

	Lithium-ion	92 -95[5]	22-350	Hours Days	High efficiency. Medium energy density. Long lifetime. Transportable.	High cost. Complex battery management system.
Mechanical	Flywheel	80-95	80-200	Seconds Minutes	Fast charge. Low maintenance costs	Low storage capacity. Short storage time. High self-discharge. Safety threats (cracks)
	Compressed air	60-70	3-6	Hours Days Weeks Months	Low self-discharge. Medium round-trip efficiency. Long storage time	Low energy density. Storage capacity constrained by geography. Limited transportability. Only large-scale units connected to grid are economically feasible
	Pumped hydro	75-82	0.27-1.5			
Chemical	Hydrogen	30-60	2,400 (liquid)	Weeks Months	Transportable. Large storage capacity. Long storage time. Low self- discharge. Low energy installation costs. High energy density. Extremely low self-discharge	High costs of electrolysers. Low round-trip efficiency. High energy consumption High power installation costs
	Ammonia	40-72 (by electrolysis)	3,194 – 4,325(liquid)			

Many of the storage options in *Table 2.1* provide storage only over short to medium timespans (e.g. electrical and electrochemical storage options). For longer-term storage, compressed air and pumped hydro are good options, however even though these technologies could potentially solve the problem of decarbonizing on-land grids, “these technologies would not be suitable to deliver energy over distances. That is why mechanical applications do not seem to be suitable for providing the ultimate solution to the challenge of large-scale, long-term, and transportable energy storage” (The Oxford Institute for Energy Studies, 2020, p.6)

Hence, experts have been looking at other large-scale, long-duration, and transportable energy storage options and suggested the use of chemical storage. This type of storage is based on substances such as hydrogen, ammonia or methane that can be used to store energy for longer periods (Valera-Medina & Banares-Alcantara, 2021). The excess energy from renewables is used to split the water and obtain hydrogen, consequently this hydrogen is stored in tanks and used when and where it is needed. Once obtained it can be used for electrification through gas motors, gas turbines and fuel cells (Power Technology, 2021).

Compared to hydrogen, liquid ammonia has similar characteristics but with higher energy density,

[5] The highest amongst electrochemical.

similar to methanol, with 45% higher density than liquid hydrogen which allows for easier transportation. Ammonia contains more hydrogen than liquid hydrogen, concerning volume[6]. According to a report from the IEA, ammonia is one of the most attractive energy carriers with significant economic advantages (Kobayashi et al., 2019):

"*A standard tank of liquid ammonia (60,000 m^3) contains about 211 GWh of energy, equivalent to the annual production of roughly 30 wind turbines on land. Ammonia can be burned cleanly; water and nitrogen are released, but not carbon*" (Proton Ventures, 2016).

The main advantage of ammonia apart from its physical properties is the large production of this gas around the world. Because it is the second most produced chemical worldwide, there is already a well-established infrastructure, in addition to the knowledge to handle, store and transport this gas safely.

Throughout this chapter we have been exploring the most popular options to produce and utilise green ammonia in the energy sector. However, there are certain limitations that we need to acknowledge about this gas, which present challenges for its current use in power generation and energy storage.

2.4. Green Ammonia Challenges

2.4.1. Safety

First, one of the barriers and the main concern for green ammonia is the safety of the gas. Several studies have been performed to demonstrate the safety aspects of this fuel. On September 2016, the U.S. Environmental Protection Agency (EPA) published a final report about the health and security effects of ammonia. The study revealed that inhaled ammonia in high concentrations could cause irritation and serious burns in the mouth, lungs and eyes. However, the penetrating smell of ammonia allows easy detection even at low concentrations which reduces the risk of people being exposed to high amounts. Additionally, there is no evidence that constant exposure to ammonia causes cancer (EPA, 2016). Nevertheless, it is important to remember that it remains a corrosive agent with toxic features which means that it needs to always be handled following strict safety guidelines.

The Risø National Laboratory in Denmark also developed a safety profile of ammonia as an energy carrier in a report called *Safety Assessment of Ammonia as a Transport Fuel* (Duijm et al., 2005), in which they compared ammonia to three different types of fuels: Liquid Petroleum Gas (LPG), gasoline and hydrogen. According to this report, ammonia applications would need to follow similar regulations as for natural gas and LPG. Additionally, they stated that the hazards concerning the production and at storage facilities of ammonia do represent a risk but only on site. The report concludes that "the hazards

[6] Ammonia (NH_3) contains three hydrogen atoms whereas hydrogen (H_2) only contains two.

in relation to ammonia, need to be controlled by a combination of specific technical and regulatory measures" (Duijm et al., 2005), if these recommendations are followed, ammonia should not represent more risk than currently used fuels.

Even though one of the advantages mentioned before was the established infrastructure around the world, the disadvantage is that ammonia has a severe corrosive impact on metals which will require additional research to avoid damaging the pipelines in the distribution process, if it becomes commercially available as an energy vector (Loginow, 2022).

Ammonia has been in the market for hundreds of years and the chemical industry has all the expertise and knowledge to handle this chemical commercially. Nevertheless, ammonia is still a hazardous gas, but under very specific conditions and circumstances. Large-scale stationary storage has proven to be safe and cost-effective thanks to its favourable physical properties (G. Wang et al., 2017).

2.4.2. Environmental concerns

An additional challenge for NH_3 as a fuel is the NOx emissions[7] (Carioscia, 2021). Even though green ammonia does not contain CO_2, when used as a fuel, if it is not burned properly, it could release NOx particles which contribute to climate change. Research is focused on this area and experts are working at developing different methods to burn ammonia with the least possible NOx emissions (Cechetto et al., 2021).

Another aspect we need to consider about green ammonia is the water intensity of the technology. As mentioned above, in order to produce green ammonia, the hydrogen required needs to be obtained from water. This demands a constant supply of pre-treated, high purity water. According to (Ghavam, Vahdati, Wilson, & Styring, 2021), 16 tonnes of water are required for the production of 1 tonne of ammonia. Additional water is required for cooling and support systems.

The water required to produce ammonia can be obtained from seawater through desalination – the process by which the dissolved mineral salts in water are removed (Iberdrola, 2022). This is advised for gigawatt–scale ammonia production. However, the use of desalination systems represents two main challenges. First, current desalination technologies (Reverse Osmosis (RO) is the leading desalination technology) can achieve recoveries of up to 50%, this means that twice the amount of water desired must be fed into the process (Beswick et al., 2021). Second, desalination processes are energy intensive and according to Kuepper, (2009) detrimental to ocean biodiversity. "In 2016 the amount of ammonia produced was reported to be 146 Mt globally. Based on this data, to produce the same amount of ammonia through water electrolysis, 233.6 tonnes of water were required" (Ghavam et al., 2021, p.3).

[7] Nitrogen Oxides (NOx) particles are a type of greenhouse gas caused when a fuel is burned at high temperatures.

This issue becomes bigger when looking at the latest ammonia projections from IRENA, where by 2050 ammonia production levels are expected to reach 688Mt (IRENA & AEA, 2022). Nevertheless, research is now underway to improve the energy efficiency in desalination processes (Beswick et al., 2021). Additionally, it is highly important to also consider this from a social point of view due to the current implications of the increasingly severe worldwide water crisis. For example, one of the countries analysed in this research is Mexico which according to the Mexican National Water Commission (CONAGUA) about 70% of Mexico is impacted by drought, causing water shortages (NBC News, 2021). This might impact the technology from a public perception aspect if the desalinated water produced for ammonia technologies competes with domestic use.

2.4.3. Power Generation

Historically, ammonia has occasionally been used as an engine fuel (Cornelius et al., 1966) but it has not been successful to date in replacing alternative fuels, especially fossil fuels.

In 1943, during World War II, due to a shortage of diesel, liquid ammonia was utilised as a fuel for buses in Belgium. Emeric Kroch developed an engine running with both ammonia and coal to keep public transport in operation. Regarding safety, there was only one accident recorded during the two years in operation and it was due to careless overfilling an ammonia tank causing the tank to explode. No further accidents were reported from the buses in those years and no injuries or intoxication were recorded (Meyer, 2012).

However, ammonia fuel was not in the market for long (1943 to 1945) and as soon as the war ended and diesel was available again, buses went back to their original type of power. The main reason for this was due to efficiency. Compared to gasoline, ammonia has about half the energy density, which implies that you would need double the amount of ammonia fuel to achieve the same distance (Meyer, 2012). Fifteen years later the US Army conducted research to develop an ammonia-fuelled gas turbine. Unfortunately, this research did not go further as they encountered a problem obtaining low combustion efficiency (Kobayashi et al., 2019).

Another example of the use of ammonia as a fuel in previous years is The National Aeronautics and Space Administration (NASA). NASA utilised liquid ammonia for a X-15 rocket-powered airplane in 1960 obtaining the record for the highest manned flight (Kobayashi et al., 2019).

Even though efforts have been made through history to use ammonia as a fuel for engines or for energy production, the technology has not reached a commercial stage yet. The main challenge, according to experts is finding economic viability (IRENA & AEA, 2022). As described above, more than 90% of ammonia is currently produced from natural gas, to shift the current production to green ammonia, electrolysis is necessary, this however, is energy intensive, has a lower overall efficiency and leads to higher costs, as electrolysers are expensive (Zhu, 2022). “CF Industries of the USA, one of the world’s largest ammonia producers, estimated that the cost to make green ammonia would be about $500/t, which is 3.3 times higher than the $150/t for brown ammonia[8]” (Zhu, 2022, p.4).

A second challenge is availability. If ammonia is used for power generation to decarbonise the current energy industry, large volumes would be needed. As described in section 2.4.1, Japan has pledge to use 3 million tonnes of low-carbon ammonia each year by 2030 to cut their carbon emissions (Financial Times, 2020). According to Kumagai & Goliya (2022) “cofiring 20% ammonia at a 1000 MW coal power plant would consume 0.5 MtNH3/y. For all coal-fired power plants in Japan to cofire 20% ammonia, 20 MtNH3/y would be required, an amount comparable to the current global volume traded” (p.5).

Significant progress in the development of ammonia technologies for power generation is in place to address these challenges (IEA, 2021). For example, research to improve electrolysers to increase efficiency and reach economic viability. Ammonia combustion systems are focused on reducing NOx emissions. Commercial demonstrations of ammonia as a fuel for ships are scheduled to be ready between 2024 -2025 (IEA, 2021).

2.4.4. Storage

The capacity of ammonia to store carbon-free energy is one of the most attractive advantages of this gas. Even though ammonia is one of the best alternatives to other energy storage technologies (as Figure 2.6 illustrates), there remain some challenges.

First, it is important to fully understand that ammonia-based technologies are still at demonstration stage. Research is still ongoing, looking for the safest, cost-effective and reliable option. As for any new alternative energy technology, the cost of implementation is still high. According to a publication from the magazine *Chemical & Engineering News* green ammonia will cost two or four times as much as conventional ammonia to produce (Tullo, 2021).

Second, it has been noted that this technology is an excellent option for long-distance vehicles, for example a transatlantic tanker, hence the interest from the maritime industry. However, for short distances it might not be the best energy storage option. Ammonia requires large tanks to store the energy and this might not be viable for short distances (Valera-Medina & Banares-Alcantara, 2021).

[8] Brown ammonia (also called grey ammonia) refers to the ammonia obtained from natural gas.

2.4.5. Market 'lock-in'

An additional challenge is the established fuel market. Currently, fossil fuels are the largest energy source around the world (Yildiz, 2018). They present several advantages over any alternative energy systems such as low cost, high reliability, and efficiency. As a new energy technology, significant market penetration of green ammonia has not yet been achieved.

Despite the global efforts to reduce the consumption of carbon-based fuels, the market is still dominated by fossil fuels. This is part of a concept known as 'lock-in', where emerging technologies, like green ammonia, struggle against the stablished fuel market. (Foxon, 2002) describes different types of 'lock-in' for emerging low-carbon technologies.

The first one is *technological lock-in*; different research has been focused on understanding technological change and how this development both influences and is influenced by the social, economic an cultural situation in which the technology is develop. Therefore, new technologies depend on the timeframe when these were developed, this concept is called 'path-dependency' and it refers to "the particular characteristics of initial markets, the institutional and regulatory factors governing the introduction of the technology and the expectations of consumers" (p.2).

The second is *institutional lock-in*; this refers to the high start-up costs of new technologies and difficulty of the institutions to change in order to allow new developments. Because formal institutions and public policies require extensive investment and coordination, it is difficult to change, once established. Modern technological systems are embedded in institutional structures, therefore, these factors leading to institutional lock-in can interact with and reinforce the drivers of technological lock-in.

The third challenge is the *carbon lock-in*; specifically for sustainable developments. The concepts of technological and institutional lock-in have important implications for the understanding of these developments and the policy framework needed to promote them. Current carbon-based energy systems (e.g. industry and transportation) in developed countries form a "locked-in techno-institutional complexes" where the concept *carbon lock-in,* was created:

> "Unruh (2000, 2002) has argued that industrial economies are in a state of carbon lock-in to current carbon intensive, fossil fuel-based energy systems, resulting from a process of technological and institutional coevolution […] lock-in occurs through combined interactions among technological systems and governing institutions." (as cited in (Foxon, 2002))

These barriers are relevant to acknowledge because they represent relevant challenges for green ammonia during its deployment, something that experts involved in green ammonia in this research are well aware of (see *Chapter 5*). According to Foxon (2002) acknowledging these barriers can "provide a framework of process guidelines to aid policy-makers to develop a more integrated mix of policy instruments to promote sustainable innovation, in order to overcome technological and institutional lock-in in the low carbon and product policy areas" (p.7).

2.5. Importance of understanding public perceptions of green ammonia

Acceptance of new energy technologies is an important consideration for those involved in its development as research on other low-carbon energy technologies has shown. For example, while nuclear energy may be a suitable option to tackle CO_2 emissions, the technology also faces several challenges with regards to public opinion, especially when related to issues like waste, safety and proliferation (Ekins, 2004). Wind energy is another example. It is one of the most promising alternative technologies with an increasing popularity around the world (Ritchie & Roser, 2019). The United Kingdom is one of the leaders in this technology with more than 11,000 MW installed of wind power capacity (Tatchley et al., 2016). While there are high levels of general public support at a national scale (European Wind Energy Association, 2009) people tend to be more reluctant at a local level, mainly during the planning and siting process (Ellis et al., 2009). What these examples illustrate is that public acceptance of low-carbon technologies is an important element to consider and there is also increasing recognition that public perspectives need to be considered early in a technology development cycle to adequately anticipate and respond to public concerns. Doing so is considered part of responsible science and innovation (Owen et al., 2012; Stilgoe et al., 2014).

In particular, Stilgoe et al. (2014) argue that technological responsibility has traditionally relied on legislative frameworks that cover health and safety as well as protection of the environment, while neglecting how innovations might interact with society in other ways. They argue that "conceptions of responsibility should build on the understanding that science and technology are not only technically but also socially and politically constituted" (p. 1569). This requires new models of anticipatory and participatory governance which expose science and innovation to a wider range of inputs, for example through constructive, real-time and other forms of technology assessment, value-sensitive design and socio-technical integration. The idea for such new forms of governance for science and innovation has resulted in the Responsible Innovation Framework as adopted by UK Research and Innovation. (Stilgoe et al., 2013).

Upstream engagement is proposed as an important part of such responsible innovation and technology development. Early engagement with stakeholders including the public to 'open-up' the discussion about motivations, visions, purposes and implementation of new technologies beyond scientific and technical features. Such early engagement with a wide variety of stakeholders is important for not only ensuring future acceptability of a technology, but also to help design it in a way can account for the ethical, social and political values that are important to affected groups and communities (Escobar, 2014). While green ammonia technologies might not face the same scale of ethical and moral questions as other innovations (e.g. geoengineering (Corner et al., 2013),, nanotechnologies (Pidgeon et al., 2011)), there are still likely to be a number of issues that may not be anticipated by technical analysis alone. Starting the process of understanding future acceptability of green ammonia now, at a very early stage, will therefore enable a more anticipatory rather than reactive approach to development and implementation of green ammonia.

Currently there are no known public engagement studies on green ammonia, and this thesis presents an initial exploration of public perceptions of the technology. It therefore is a first attempt at understanding what benefits, risk and concerns people perceive about the technology and how this might differ to experts in the technical aspects of green ammonia. It is important to note that this thesis represents an initial public engagement exploration, and there remain many unanswered questions. This is reflected upon throughout the thesis in the limitation sections of the empirical chapters and the final discussion chapter. It is hoped that future researchers will build on this study to explore these further questions.

Even though there are no currently known studies on public perceptions of green ammonia, there is much literature on the acceptance of low-carbon energy technologies and similar fuels such as hydrogen. The next chapter discusses this literature with a view to inform the empirical work of this thesis.

2.6. Summary

Ammonia is a potential fuel for a carbon-free future; it is the second most produced chemical in the world, and it can be generated from air and water. It presents several advantages over any other gas such as high-energy density, the potential to be stored in large quantities over an extended period of time and being used for power generation while at the same time being used as a chemical. Its current deployment and versatility allow any country to produce, store and distribute this gas. However, disadvantages such as high costs, lack of technology development, restraints to a widespread deployment of renewable energy and public perception, may slow down the potential of green ammonia.

Although this scenario might look challenging, it is a reality that green ammonia interest and investment is increasing worldwide. Countries are adopting this technology as a measure to tackle GHG emissions. As renewable energy technologies keep growing, the need to store excess energy follows the same path, providing opportunities for green ammonia as a new technology to store and transport excess energy. Even though several barriers have to be overcome in the next coming years, and further research has to be carried out in this matter, acceptance from the public will be a key aspect for successful development and implementation of green ammonia. Therefore, this research is the first study to focus on public perceptions and attitudes towards green ammonia for energy storage and energy power.

The next chapter will present a review of the relevant literature for the research. It provides an overview of the body of knowledge in the areas of public perception and risk perception of low-carbon energy sources, emerging technologies, and current research on public perceptions of hydrogen and ammonia as a chemical. It introduces relevant frameworks and theoretical concepts to the present research on green ammonia and its objectives.

Chapter 3. LITERATURE REVIEW

3.1. Introduction

This chapter presents the literature review relevant for the research in this thesis. The chapter is divided into four sections with various thematic subsections, providing an overview of the body of knowledge in the areas of risk perceptions and public perceptions, low-carbon technologies and emerging technologies. This chapter has the aim to introduce relevant theoretical concepts for the present research on green ammonia and in line with the study's objectives introduced in *Chapter 1*.

The literature focuses on concepts that are relevant to exploring public perceptions of green ammonia as an emerging technology. It first defines factors related to this topic such as beliefs, attitudes, public acceptance and acceptability (**3.2**). Consequently, this section provides an in-depth discussion of public acceptance of low-carbon energy sources introducing relevant frameworks and factors for the study of public perceptions of green ammonia.

The second section (**3.3**) focuses specifically on public perception of emerging technologies. Providing further literature on different aspects that should be considered when analysing these types of technologies: Preference construction, pseudo-attitudes, information -provision and framing are examined in this section.

The third section of this chapter (**3.4**), expands briefly on the topic of risk perception and providing background information about the differences between risk perception of experts and laypeople. It introduces literature on perceptions of the general public in the chemical industry to conclude with specific studies related to hydrogen and ammonia technologies.

The last section (**3.5**) briefly presents current research on climate change (CC) perceptions discussing the results of international surveys about this topic. This section also discusses the importance of analysing CC knowledge, causes and beliefs as relevant to the objectives. It concludes with the theoretical framework (**3.6**) connecting all the concepts to the objectives from *Chapter 1*.

It is important to highlight that, while there is extensive research on CC and public perception of upcoming energy technologies, so far, there has been no detailed assessment of people's understanding of ammonia-based systems. Instead, related topics have been analysed in more detail such as hydrogen and alternative energy systems. For this reason, all of the topics presented in this thesis are relevant to get a first idea about how people will react to the concept of 'ammonia energy technologies'.

3.2. Defining key concepts: From public perception to public acceptance

"Public opinion claims to be the voice of the people, a clear and direct utterance from the citizenry […]"
(Glasser & Salomon, 1996)

This thesis analyses public perception of ammonia as an energy vector and storage; the main theoretical concepts that are useful for this endeavour are outlined and discussed below. Particularly, we will analyse the meaning of 'public perception' and concepts linked to it, such as beliefs, attitudes, opinions and consequently, public acceptance and acceptability.

First, *perceptions* are defined in the context of social psychology as "how someone sees and understands the world around them and hence constructs his/her own view of something (which could include emotions and more affective experiences)" (C. C. Demski, 2011). When referring to *public perception* throughout this thesis we would understand it as "*the aggregate views of a group of people […] who are asked directly what they think about particular issues or events*" (Dowler, Bauer, Green, & Gasperoni, 2006).

Nevertheless, it is important to also understand additional factors related to *public perception* and that are used throughout this thesis to describe how the public perceive or accept certain technologies. Below, beliefs, attitudes, public acceptance, and acceptability are described in more detail.

Beliefs refers to the "thoughts or attributes associated with an attitude object" (Maio et al., 2019) e.g. Ammonia as a fuel is very dangerous. According to Demski, (2011) *beliefs* is a very similar concept to *perceptions*, and both are implicated in the make-up of an attitude or opinion.

Attitude can be understood as an "overall evaluation of an object that is based on cognitive, affective, and behavioural information" (Maio et al., 2019, p. 526) and can describe a person's favourable or unfavourable position towards something (Demski, 2011) e.g. I do not like ammonia. This is often used interchangeably with *opinions.* Hollander (2008), clearly differentiate between these two concepts by describing that while an attitude is a durable orientation towards some object, an *opinion* is the visible expression of it.

Analysing the perception of public towards a technology allows us to determine preferences and assess what might influence public acceptability and support (Spence et al., 2021). Throughout the studies and frameworks cited in this chapter we will observe that the concepts of acceptance, acceptability, social acceptance and social support are terms frequently applied to describe how the public may respond to the implementation of a certain technology

According to the Cambridge Dictionary *acceptance* can be understood as “a general agreement that something is satisfactory or right” (2022). In this thesis, however, we refer specifically to *technology acceptance*. In their technology acceptance model, Huijts et al. (2012) further distinguish between *acceptance* as “the behaviour towards energy technologies” and *acceptability* as “an attitude (evaluative judgment) towards new technologies and attitude towards possible behaviours in response to the technology” (p. 526). It is also important to highlight that acceptance is not the same as support. Acceptance, as stated in the work of Huijts et al. (2012) is a “behaviour that enables or promotes (support) the use of a technology, rather than inhibits or demotes (resistance) the use of it” (p.526). According to Sven Vlassenroot et al. (2008) acceptance and support are strongly related; however a relevant distinction has been made when referring to political, policy and social support. They state that there can be acceptance, but this would not necessarily lead to the support. “For example: it is possible for an individual to accept paying taxes, but he would not necessarily support it. In this way acceptance must be seen as a precondition to come to support but would not be the same.” (p.2). This thesis mostly focuses on what Huijts et al. (2012) calls acceptability (i.e. attitude) rather than acceptance (i.e. behaviour) because green ammonia is not yet commercially available. Also, it is important to note that there are different types of acceptance, some of them are citizen, consumer, or socio-political acceptance. This is further discussed in the theoretical frameworks below.

It is important to clarify that defining and analysing public perceptions and what drives the public to accept or oppose a technology is a complex task. Although is indicated above that we are referring to “aggregate views of a group of people…” when referring to public perceptions, there is not a clear or direct way to assess entirely true beliefs of the members of the public.

This implies that perceptions will be reliant mostly on the individual and the specific time and context in which the research was carried out. Individual perceptions are context-dependent (certain beliefs are more clearly understood in some situations than others) (Dowler, Bauer, et al., 2006). Consequently, this chapter discusses different factors that have been found to be important for public acceptance of new energy technologies and that are analysed throughout the research.

3.2.1 Public acceptance of low-carbon energy sources

Considering that this research analyses green ammonia as a potential energy vector and taking into account the novelty of this technology, it is important to consider previous studies about different low-carbon energy technologies along with concepts and theories supporting these findings. Several examples about the importance and how public perception can shift the development of low-carbon energy technologies and what elements play an important role are presented below highlighting the relevance of this type of research, as well as providing us with a theoretical framework to understand public acceptability of low-carbon technologies.

Perhaps the most common and known example regarding challenges of public acceptance is nuclear energy. Nuclear incidents like the one in Fukushima in 2011 have caused acute negative perceptions from the public, with more than 250,000 people in Germany marching and asking to shut down all reactors in such a country. A couple of months later, the petition was granted and the eight reactors owned by Germany were programmed to be closed by 2020. Italy, Israel and Indonesia have also seen negative public reactions after the incident (Hickman, 2011).

Poortinga, Aoyagi, and Pidgeon (2013) analysed numerous national representative surveys from before and after the Fukushima accident to examine the impact on public perceptions in Britain and Japan. Before the accident both countries had ambitious plans to expand nuclear power as a strategy to reduce CO_2 emissions. However, results indicate that whereas the perception of British population remained stable over the time, the Japanese public appear to have completely lost trust in nuclear safety and regulation. Nuclear energy in this country is no longer considered an acceptable option. This study demonstrates the importance of trust in the technology's safety for the public. This is relevant for the present research due to the novelty of the concept of green ammonia where an accident could jeopardise its deployment.

Another interesting example is wind turbines in the United Kingdom (UK). Despite several positive outcomes for the environment and other benefits compared to other alternative energy options, there is a relatively high a level of public opposition to wind farms in the UK at a local level. British residents understand and support renewable energy from wind at a national level, however they have additional concerns when it comes to considering developments in their own areas such as aesthetics or how it fits into the landscape[9] (Jones & Eiser, 2010). Researchers from this study point out that even though the factor of spatial proximity to the development was important when predicting resistance (e.g., a gradual increase in positive attitudes towards the development with increasing distance from the identified sites) attitudes were determined by more than just proximity. Factors related to self-interest and ignorance were found, for example "as soon as the development is anticipated to be 'out of sight' it will likely be

[9]Often refered as NIMBYSM (NIMBY: Not in My Backyard) - Positive attitude towards the technology but not acceptance of the development of this in their neighbourhood.

considered in largely terms, and hence deemed relatively acceptable (even in comparatively proximal locations)” (p.11).

These examples illustrate the importance of public acceptance in the deployment of low-carbon technologies. As we can observe, factors related to the acceptance or opposition of a certain energy technology are not always related to the benefits (or lack of them) that the technology can provide, but rather on how the public perceive the technology and the context in which it is developed and deployed. Therefore, understanding how people form an opinion and what elements are involved to support or oppose an energy technology has become the focus of a lot of research in social psychology in recent years.

This has resulted in an extensive literature on public acceptance and acceptability of low-carbon energy technologies. As Upham et al. (2015) states: “The number of relevant studies is substantial: even the number of nationally-specific studies, i.e., in a single country, can run to hundreds and span public attitudes and levels of acceptance with respect to nuclear energy, hydrogen, CCS, wind, biomass plants and other renewable and low carbon energy technologies.” (p.3)

Given these technologies are already commercially available, much of this literature examined public acceptance of the implementation or siting of technologies in particular contexts and places. This makes it quite different to green ammonia technologies, which are not yet commercially available. Nonetheless, the literature on public acceptance of low-carbon energy technologies has provided a number of conceptual frameworks, which are helpful in situating and shaping the current research.

One such framework has been proposed by Boudet (2019), who summarised the dominant factors that researchers have identified as shaping public perception of new energy technologies, *Fig.3.1*. The first factor is **technology,** for public elements such as risk/benefit ratio of the energy project, cost (realted to energy prices), impact on the environment, how it looks, dread risk and observability, are essential aspects when forming an opinion. The second factor is **people,** this relates to how sociodemographic variables are going to impact on risk perception, for example age, gender, age, education level, political orientation social norms and values, among others. Also, it accounts the role of trust in both the industry and the government to develop energy projects. The third factor is **place**, as discussed previously place attachment is going to play a significant role on risk perception. Aspects like history (if there has been any accidents with a similar technology) or the impact on the landscape are going to influence (e.g, Fukushima). The last factor is **process**, this aspect realtes to transparency in the development of the project, how much general public are taken into account, perceived fairness and economic involvement (appropiate compesantion or favourable leasing terms). Even though this four dimensions are displayed seperately, it is noted by the author that there is an interaction between them.

between them.

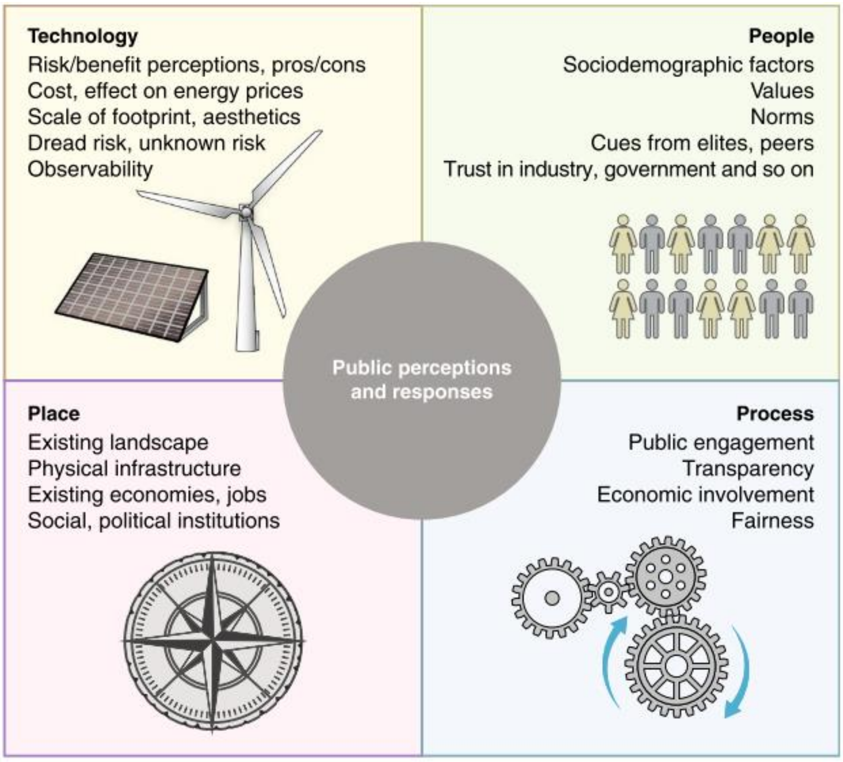

Figure 3.1. Factors affecting public perceptions and responses to new energy technologies (Boudet, 2019)

Some of the concepts in Figure 3.2 will be useful in the context of understanding public perceptions of green ammonia as an emerging low-carbon energy technology. In particular, factors associated with the *technology* and *people* categories such as risk and benefits perception, impact of sociodemographic variables, trust in the role of industry and government to develop the energy project, among others. However, due to the novelty of green ammonia, *place* and *process* cannot be analysed further as the technology is not at a commercial stage yet (although the national context in which green ammonia may be developed is considered). These concepts will however become relevant once ammonia-based energy technologies are ready for deployment and future research need to consider these when this becomes a reality.

Another framework for understanding acceptance of low-carbon energy technologies is that of Wüstenhagen et al. (2007), which focuses on renewable energy acceptance and incorporates three dimensions of social acceptance, some of which overlap with those of Boudet's work: socio- political acceptance, community acceptance and market acceptance (Figure 3.2):

Figure 3.2. The triangle of social acceptance of renewable energy innovation (Wüstenhagen et al., 2007)

Socio-political acceptance: This dimension refers to the general level of social acceptance. Essentially, this concept is the perception and interaction between the general public, policy makers and stakeholders. Consequently, this dimension will influence the community and market acceptance. First, the general public manifest their approval for a development of a certain technology or an energy policy, which usually is followed by the support of certain stakeholders to create or support such policies (Lewenstein, 2002) (Spence, Demski, Butler, Parkhill, & Pidgeon, 2015). Most of the countries currently have clear targets to reduce their CO_2 emissions through the expansion of renewable technologies. However, these targets do not necessarily represent positive scenarios for these technologies. In this dimension, the key stakeholders should be willing to generate institutional changes and policies that create favourable conditions for these new technologies. Linking this with Boudet's framework, factors relating to the technology and people categories (e.g., risk and benefit perceptions, trust) are also important for socio-political acceptance as delineated in Wustenhagen's model.

Community acceptance: The dimension refers to the local acceptance of the technology. Even when accomplishing socio-political acceptance, this fact does not guarantee that local residents will approve a certain energy alternative as wind energy studies in the UK have shown. For example, 48% of applications for onshore wind farms in England and Wales were rejected because of public opposition in 2010 (Wolsink, 2012). For this reason, being able to achieve renewable energy targets while taking into consideration public preferences is a challenge for policy makers. Community acceptance in this framework covers similar factors to those in the place and process categories in Boudet's model.

Market acceptance: As the name implies, this dimension refers to a more economic perspective such as pay models, diffusion of new technology in households and corporate organizations. The dimensions oversee the views of a potential consumer/adopter community that will utilize such technologies. Goods or services that attract sufficient market demand are most likely to be retained and to ‘diffuse’ through the population while others are discarded (Slavin, 2011).

This research aims to study mainly the general level of social acceptance as part of the *socio-political acceptance* dimension. Through the analysis of the general public and expert perceptions, the research intends to provide an understanding of the interactions between these two groups regarding green ammonia perceptions. These results will also provide a clearer understanding to any support or opposition for the technology that could arise when the technology gets to a commercial stage where aspects such as trust will become more important. This will be relevant for what Wuestenhagen et al. call *community acceptance*.

Building on these frameworks, Upham et al. (2015) provides guidance on how to understand social acceptance specifically in relation to energy technologies, infrastructure, and applications. Similar to the frameworks above, they understand social acceptance of a technology as encompassing three levels:

(a) Macro level: acceptance at the general, policy or country level
(b) Meso level: acceptance at the community, town or geographically defined level
(c) Micro level: acceptance at the individual, household or organisational level

They also highlight the importance of understanding social acceptance as a multi-actor phenomenon and go on to characterise three actor groups including a) public acceptance such as acceptance by consumer or citizens, b) stakeholder acceptance, and c) political acceptance (policy support at government and political institutions).

Table 3.1 (reproduced from Upham et al, 2015), summarises these two dimensions of social acceptance to form a three-by-three grid highlighting the complexity of understanding social acceptance of technologies. The research in this thesis focuses predominantly on the macro level, and the public as the relevant actor group with some insights also provided for the stakeholder group in the forms of expert interviews. At this macro level, acceptance research according to Upham et al. (2015) “has typically sought to understand the levels of social (including the general public, policy makers, civil society organizations, experts, private organizations, etc.) acceptance at the country, state or regional level towards a particular energy supply technology. The technology is typically considered in general and in aggregate. For example, a particular country may or may not accept (invest, support, etc.) nuclear energy or offshore wind. Individuals and representatives in this country may perceive that the technology may, or may not, be acceptable at a general level.”

Table 3.1. Actor groups and social acceptance at the three levels (Upham et al., 2015)

		Level		
		General/Policy	**Local/Community**	**Household/Organisation/ End User**
Actor group	**Political**	National acceptance (by national, formally instituted decision makers)	Local political acceptance (by local, formally instituted decision makers)	User acceptance (by individual citizens with views on energy policy)
	Stakeholder	Stakeholder acceptance (by other nationally active market and nonmarket policy groups)	Local stakeholder acceptance (by other locally active market and nonmarket policy groups)	Stakeholder acceptance (by commercial and other organized users)
	Public	Public acceptance (by the general population as citizens with views on national policy)	Local public acceptance (by the local population as citizens with views on national policy)	End-user acceptance (by household, organization and individual end-users)

Upham et al (2015) also propose the importance of examining the internal structure of individual acceptance such as factors that lead to actual behavioural acceptance or use of a technology. For this, it is useful to summarise the technology acceptance model proposed by Huijts et al. (2012a), which summarises psychological factors that influence attitudes (acceptability) and behaviours (acceptance) towards technologies. This model (reproduced in Table 3.1) provides a summary of key psychological factors shaping public responses, some of which will be relevant to understanding public acceptability of green ammonia at the general level as defined through Upham et al's framework. Although the authors orient this framework for understanding citizen and consumer acceptance (e.g., public's response to the building of energy infrastructure or purchasing and using energy technologies) rather than socio-political acceptance as investigated in this thesis, there are still useful factors to consider, especially those that predict the attitude component of the model. In particular, the framework stresses the importance of understanding people's overall evaluations of costs, risks and benefits and positive and negative feelings relating to a technology. They cite numerous studies on acceptance of carbon capture and storage as well as other types of technologies (e.g., Steg et al., 2005; Moula et al,. 2013; De Best-Waldhober et al,. 2011; L'Orange et al., 2011; Kim et al., 2014; Achterberg et al., 2010; Aas et al., 2014; Zoellner et al., 2008; Soland et., 2008) where perceived risks and benefits were predictive of people's attitudes towards the technology. As such, we can be relatively confident that understanding risks and benefit perceptions are important factors also for understanding initial attitudes towards green ammonia. In addition, positive or negative affect when thinking about a technology was also influential for understanding attitudes (section 3.4 discusses these factors in more depth).

Perceived fairness and trust are further factors that are important for understanding people's attitudes towards a technology, although the model includes these mostly focusing on contextual factors (e.g., perceived fairness of how the technology is implemented). Trust is also relevant at the general socio-political level because it includes trust in actors who are responsible for the technology, which in turn predicts perceived risks and benefits and affective responses to technologies such as nuclear, nanotechnology or hydrogen. If trust increases, so does acceptance.

In summary, the four frameworks reviewed in this section point to similar concepts important for understanding public acceptance of green ammonia at the socio-political level – socio-demographic variables, risk and benefit perceptions, affective responses, and trust. These factors are discussed further in the following sections.

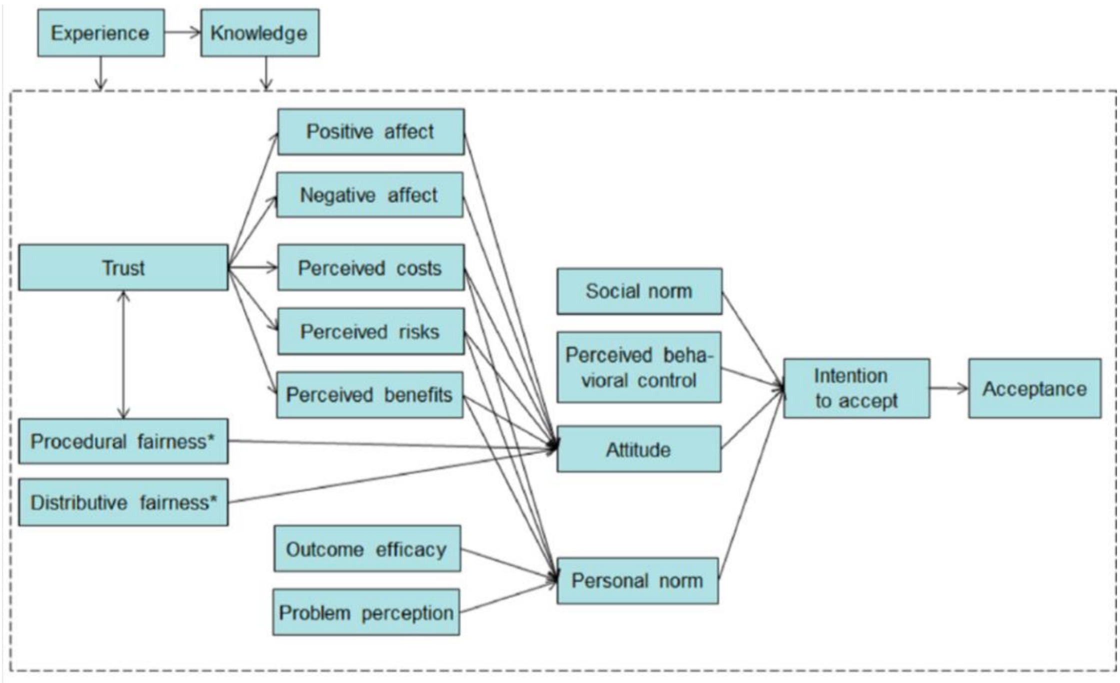

Figure 3.3. A schematic representation of the technology acceptance framework (retrieved from Huijts et al., 2012a)

3.3 Understanding Perception Emerging Technologies

Green ammonia technologies are only emerging, and the public is unlikely to have much familiarity with it, unlike other low-carbon energy technologies such as wind or nuclear power. As such, it is useful to consider in some more depth the literature on public perception of emerging technologies –

technologies where people have little awareness and familiarity and therefore do not have fully formed opinions and attitude.

3.3.1 Preference construction and pseudo-attitudes

An example of an emerging technology that has developed this literature is that of Carbon Capture and Storage (CCS). CCS is an emission reduction process that involves capturing CO_2, compressing it for transportation and then inject it deep into long-term geological storage (International CCS Knowledge Centre, 2022), this emerging bridging technology is recognised to be a key element for the reduction of GHG emissions (Ghaleigh, 2016). Research on CCS has been increasing over the last decade with several studies focusing on the topic of public perception. Results from CCS literature is useful for this thesis because it provides knowledge about variables that can be applied for green ammonia technologies. L′Orange Seigo et al., (2014) presented a synthesis of 42 articles regarding public perception of CCS and structuring it around Huijts et. al framework presented in section 3.2.1 above. According to the authors the best predictor of acceptance for CCS is benefit perceptions, a common result observed for acceptance of emerging technologies. Perhaps unsurprisingly, the analysis also shows that participants often request more information about other alternatives and are concerned about the unsustainable nature of the technology. We will observe similar results for other emerging technologies such as hydrogen (see below e.g., Flynn et al. (2010)) where people are generally favourable towards its use but also request more information about other technologies as a comparison.

According to a study about nanotechnology carried out by (Pidgeon et al., 2012), when the general public is presented with situations of low familiarity (like in the case of green ammonia), people still tend to offer responses to research questions, even if their knowledge is limited. Participants from the study reported to be unfamiliar with the topic of nanotechnology, however they believed these technologies will contribute positively to society in the long run. The authors concluded that participants tend to undergo a process of 'preference construction' as they answer questions on unfamiliar technologies and ideas. They define preference construction as a process "where people, faced with a survey question about a topic they are initially unfamiliar with, arrive at a response drawing upon a range of their existing beliefs and values, their instant affective responses, and a range of inferences about what the question being posed to them might mean or be analogous to. Such responses are a product of the person's attempts to make sense of an unfamiliar issue, informed by what they already know and their inferences from the wider context and cues within which a question is asked" (p.16).

This concept of 'preference construction' is very relevant for the research presented in this thesis. Even though we are aware that green ammonia will be a new topic for most of our participants, we believe that when presented with the concept, the general public will respond in a similar way as the study cited previously about nanotechnology– when faced with an unfamiliar topic participants will arrive at a response drawing upon a range of their existing beliefs and thoughts about the topic. For this reason, studies on emerging technologies often include qualitative methods because in enables participants to voice their initial perceptions and concerns in their own words. Similarly, survey studies on emerging technologies include components such as open-ended questions, which attempt to capture people's initial impressions of a technology that is presented to them (Pidgeon et al., 2012). This thesis adopts a similar approach for capturing initial perceptions of green ammonia (see empirical chapters).

Nevertheless, it needs to be recognised that a challenge regarding analysing perceptions of an emerging technology is obtaining *pseudo-opinions* –"weak and non-directive evaluative judgements that people provide in responses to questions about things they know" (Jones et al., 2017, p.285). As pointed out by the authors qualitative methods reduce the chances of recording this type of opinion as it provides participants with more information, allows participants to clarify their understanding before eliciting an opinion. The goal is not necessarily to capture fully formed attitudes but rather perceptions of risks and benefits that may in turn inform an eventual attitude that people form towards the emerging technology (as per Huijits et al's model).

Lee, Scheufele, and Lewenstein (2005) also found similar results as Pidgeon et. al. and reiterate the importance of capturing initial feelings (e.g., affect in Huijts et al's 2012 model) evoked by a technology. Data from a national telephone survey in the U.S. about public attitudes toward emerging technologies, such as nanotechnology, found that "emotional heuristics moderate the effect that knowledge about nanotechnology has on people's overall attitudes toward nanotechnology, with knowledge having a weaker effect on attitudes for people who do show strong emotional reactions to the topic." (p.242) The role of affect is further discussed in the section on risk perception below.

On the other hand, a study carried out by (Hayashi, Hondo, & Moriizumi, 2016) in Japan, analysed the process of preference construction for renewable energies (solar power, wind power, small-scale hydroelectric power, geothermal power, wood biomass, or biogas as energy sources) before and after providing participants with information. Results suggest that even though the Japanese public is not familiar with energy problems and "tends to exhibit unstable preferences in its energy decisions" (p.2). When provided with further information (e.g. CO_2emissions, job creation or electricity generation costs) about these technologies, individual preferences developed quickly. This research illustrates how even though a technology might be unfamiliar to participants, and the decision could be mainly based on initial affective responses, information provided about the technology also plays an important role. People tend to use the information they are given to help them come to an opinion about the topic. Information-provision is therefore another important aspect of researching perceptions of emerging technologies, but research has also shown that the framing of this information can affect people’s responses.

3.3.2 Information-provision and framing

Information provision is often necessary when examining public perceptions towards emerging technologies, but studies have also shown that it is important to consider what effect this information has on people’s responses. Whitmarsh, Xenias, Jones (2019) carried out a large-scale international experimental public perception study of CCS. The study analysed how individual, geographical, and informational factors influence support for the technology. Focusing on the informational factors, the authors concluded that different forms of information and framings influenced CCS support. In general, CCS attitudes were moderately positive, however, when it was paired with other energy sources, results for support differed. For example, when CCS was paired with bioenergy, results revealed higher levels of support, whereas when pairing it with shale gas, underground coal gasification and heavy industry, support was lower. Additionally, support was lower after information regarding costs was presented. During the survey participants were also exposed to CCS framed as (a) business as usual and (b) with carbon dioxide utilisation or (c) with lifestyle change. Results suggested that framing (b) – carbon dioxide utilisation - leads to greater support than the other two options. This study clearly shows that information provision and framing of a technology can impact on people’s attitude towards it. Nonetheless, it also showed that other factors are important. For example, the authors found that country of residence was the strongest predictor of CCS support, illustrating the importance of cross-cultural research, like the one provided in this thesis.

Considering the properties of green ammonia as a storage medium, a relevant study for this research regarding energy storage and emerging technologies was carried out by Jones, Gaede, Ganowski and Rowlands (2018). Through an online survey, perceptions of grid-scale electrical energy storage technologies (ESTs) were analysed. Results revealed that respondents were positive towards energy storage in general, preferring pump hydro storage. These results are relevant for the current study because participants in focus groups and surveys will be presented with a list of benefits, where green ammonia is described as an option to store excess energy from renewables. Based on this study we can expect that this framing could lead to positive attitudes.

A further example is an online study in the UK, which analysed the effect of framing geoengineering technologies- the deliberate large-scale intervention in the Earth's natural systems to counteract CC (Oxford Geoengineering Programme, 2018) by comparing them to natural processes; they concluded that “participants who read a description of geoengineering technologies as analogous to natural processes were more likely to support geoengineering as a response to climate change” (Corner &

Pidgeon, 2015). This study further demonstrates that information can frame the technology in different ways, and this leads to more or less favourable perceptions and attitudes by participants.

This is particularly relevant for green ammonia because some information provision will be necessary to establish basic understanding of what the technology is aiming to achieve (i.e. why it is being developed). Inherent within this information will be information about climate change because green ammonia is being developed as a low-carbon fuel and storage option. According to the above research, this framing of climate change and use with renewables may lead to more favourable responses of the technology. The research in this thesis did not have the aim to examine different framings of green ammonia and how this affects public preference construction, however the role of information provision and framing of green ammonia will be discussed in more depth in the final chapter. The methodology (see Chapter 4) was also developed in line with recommendations from the emerging technologies literature, especially the inclusion of qualitative components and open-ended response questions in the survey to capture people's initial associations and reactions to information about green ammonia.

3.4 Risk Perception

How people perceive risks and benefits of a technology is important for understanding low-carbon and emerging technologies, as the previous sections have shown. This section provides some further information on how risk perceptions have been theorised and measured in past studies, which will be helpful for developing risk perception measures towards green ammonia.

Pidgeon (1998) defines risk perceptions as "people's beliefs, attitudes, judgments and feelings, as well as the wider social or cultural values and dispositions that people adopt, towards hazards and their benefits." (p. 5). Analysing and understanding risk perception provides the basis for understanding and anticipating public responses towards hazards and enables the communication between experts and decision-makers (Slovic, 2016).

Experts have developed different models to analyse risk perception , such as, the Protection Motivation Theory (Rogers & Pretince-Dunn, 1997), Fear-as-acquire Model (Hovland et al., 1953), the Parallel Process model (Leventhal, 1970), the Extended Parallel Process Model (Witte, 2009), Risk Perception Attitude Framework (Rimal & Real, 2003), Cultural Theory of Risk (Douglas & Wildavsky, 1982) and the Psychometric Paradigm (Slovic, 2016).

Perhaps one of the most well-known theoretical framework for understanding risk perceptions in environmental psychology is the 'Psychometric Paradigm'. This theoretical approach views risk as an aspect “subjectively defined by individuals who may be influenced by a wider array of psychological, social, institutional and cultural factors” (Slovic, 2016). The current research will not use this theory as a leading framework; however, it is important to recognise the most important factors of this theory that are frequently used in the study of risk perception. As described in *Chapter 1*, this is an exploratory first study in the area of green ammonia and aims to provide a basis for future research and development of the technology.

The framework was initially developed by Slovic, Fischoff and Lichtensteinn in 1984, providing an analysis of public attitudes toward various hazards. This paradigm was born due to the necessity of quantifying people’s responses to various risks and identifying the qualitative characteristics that lead to specific judgments of risks (Gorman, 2013). It is based on the principle that *risk* means different things to different people.

The classic version of this paradigm consists of asking participants to evaluate different hazards, for example nuclear waste, on various attributes (controllability, certainty, reversibility, etc.). Responses are then combined across participants to obtain the mean of each hazard on each attribute. The aggregated attribute ratings are then factor analysed to identify dimensions that underlie the attributes. Often perceptual maps are created to visualise how the hazards vary across multiple attribute dimensions. Multiple regressions are performed at the end to assess the extent to which the attribute dimensions predict key outcomes (Truelove & Gillis, 2018)

One interesting aspect that research on the psychometric paradigm has discovered, is the difference between risk perceptions of lay people and experts (Siegrist, Keller, Kastenholz, Frey, & Wiek, 2007). Through a survey distributed in Switzerland to members of the public (laypeople (N = 375) and experts (N = 46)), Siegrist et al. examined perceptions of 20 different nanotechnology applications and three non-nanotechnology applications were examined. Results suggest that experts and laypeople differ in their perception of risks associated with nanotechnology hazards. Trust, perceived benefits and general attitudes toward the technology influenced the perceived risks of laypeople in line with the theoretical frameworks reviewed in previous sections. For experts, trust in governmental agencies was an important predictor of perceived risks. They concluded that public concerns about nanotechnology would diminish if measures were taken to enhance laypeople’s trust in governmental agencies. Furthermore, results show that the psychometric paradigm can be modified for use in examining laypeople’s perception of new and emerging technologies. The importance of trust and differences in risk perceptions between experts and the public are considered further below.

Despite the fact that the ‘psychometric paradigm of risk perception’ is a well-known approach and employed frequently to evaluate public perception of energy technologies (Wang & Kim, 2018). Some experts argue that there are some factors that the classic psychometric model excludes, for example, the importance of cultural context - it does not explore in detail the social and cultural influences on risk perception such as those included in the model by Renn and Beninghaus (Bronfman et al., 2008) (Rippl, 2002).

Culture represents an important role in people's lives, it comprehends the social behaviour and norms found in human societies, as well as their attitudes and thoughts (Ilesanmi, 2009). Research on environmental psychology suggests that risk perception is specific to culture and place (Taylor et al., 2014). The '**Cultural Theory**' suggests that people decide to focus on certain hazards according to the 'culture' they belong (Douglas & Wildavsky, 1982). The evaluation of risks will be related to the individual's social and cultural context. In comparison with the psychometric paradigm, risk perception will be reliant mostly on cultural biases (social context), rather than the individual's cognitive process (Oltedal et al., 2004).

According to this theory, it is possible to predict how society will perceive a determined hazard depending on their cultural context. The approach is based on the idea that social participation can be understood by the dynamic between two dimensions, group and grid. *Group* refers to whether an individual is member of attached social groups and how absorbing the group's activities are on the individual. *Grid* refers to what extent a social context is restrictive in regard to the individuals' behaviour (e.g. a trial) (Oltedal et al., 2004).

When these dimensions are taken into account four outcomes occur, representing each, different kinds of social interactions with a unique approach of risk perception (Rippl, 2002).

1. Hierarchy: Assumes risks as long as those risks are justified by governmental authorities or experts.
2. Egalitarians: Oppose risks that will inflict irreversible dangers on many people or on future generations. They distrust risks that are forced on them by the decisions of a small elite of experts or governmental authorities.
3. Fatalists: have a strong orientation toward socially assigned classifications, but without a group deification. They try not to know and not to worry about things that they believe they can do nothing about.
4. Individualists: perceive risk as opportunity. New technologies, for example, are viewed more as possibilities and less as dangers. They do fear risks that could limit their freedom.

If a person in a society does not belong to one of these groups then he/she is part of a fifth dimension that is not taken into account as it will be assume that it has cut all social interactions.

Cultural theory is an important framework for risk perception, it allows us to understand "how groups in society interpret danger and build trust in institutions creating and regulating risk" (Tansey & O'riordan, 1999). Nevertheless, it also has been a target of criticism. According to Rippl, S. (2002) this theory is an 'overly individualistic' approach reduced to a few questions on a survey that could potentially be included in a survey following psychometric research.

Additionally, the theory is focused on social interactions and worldviews so it is unlikely that it would be able to predict risk perception in specific situations, explaining only a minor part of the variance in how people perceive risks (Oltedal et al., 2004), meaning that 'cultural theory' is not designed to explain the process of change. A such, it has been suggested that cultural theory should be seen an approach mainly of heuristic value instead of an absolute analytical tool (Tansey & O'riordan, 1999).

In an attempt to bring together some of the frameworks mentioned before, Renn & Benighaus (2013) developed the Four Context Levels of Risk Perception which captures what they believe to be the key influences on people's risk perceptions of hazards and technologies. This includes psychological, social and cultural factors at both collective and personal levels. Figure 3.1. illustrates their framework summarising four context levels including cultural background (e.g., worldviews), social-political institutions (e.g., trust), cognitive-affective factors (e.g., knowledge, beliefs), and heuristics of information processing. This framework illustrates that people's risk perceptions are determined by a complex interplay of cultural and personal factors and context. In the context of this thesis, it is useful in illustrating some of the relevant factors important for understanding risk perceptions and it draws similarities with the frameworks presented at the start of this chapter. In particular, it also highlights the importance of affect as a form of heuristic processing, and the role of trust at the socio-political level (in addition to risk and benefit perceptions at the individual cognitive level). Each is now discussed in turn.

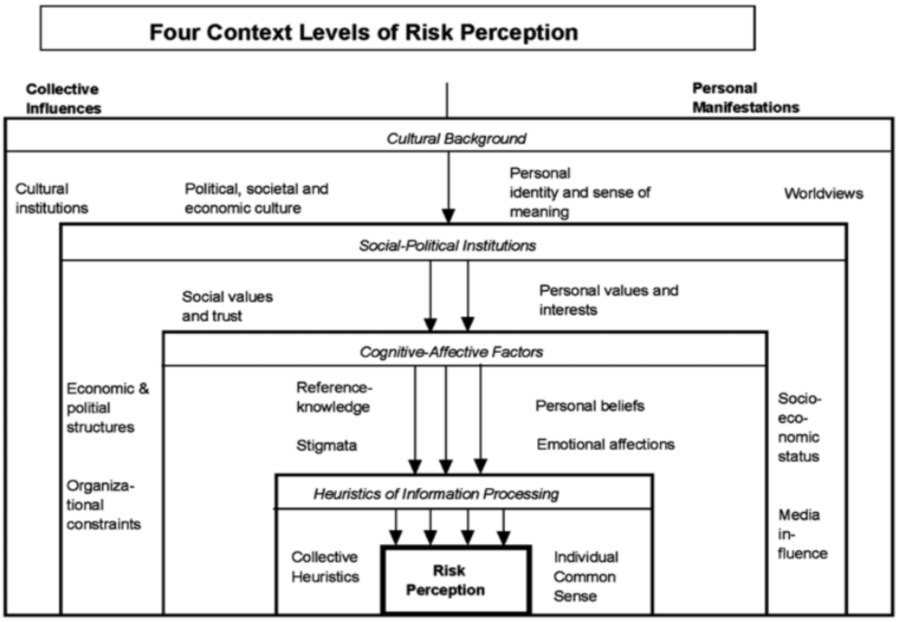

Figure 3.4. Four context levels of risk perception (Renn & Benighaus, 2013).

Affect has been discussed as an important way people perceive risks and technologies. In the literature on risks as feelings, affect is defined as a specific quality of "goodness" or "badness" and experienced by people as a feeling state (Slovic et al., 2004). The affect heuristic states that people experience these affective responses to a stimulus quickly and automatically. Slovic et al. further theorise that when people are presented with a stimulus and are required to respond to it (e.g., a question about their initial impressions of a described technology on a survey), they consult their 'affect pool' which contains images and associated affect (both positive and negative) associated with the stimulus. People can use this affect pool to provide a quick answer based on a 'gut feeling'. To capture people's initial associations, images and affect associated with ammonia and green ammonia technologies, suitable questions have been included in the empirical aspects of this thesis (e.g., open-ended questions asking for initial impressions).

Trust refers to the reliance of someone or something for decision-making about risk. In social psychology, trust is understood as the "confidence that a person or group has in the reliability of another person or group" (APA Dictionary of Psychology, 2020). Trust is an important aspect that influences risk perception and acceptance of hazards and technologies, especially when people have little knowledge or information to go on which is often the case with novel and emerging technologies. Trust is a way for people to judge whether the risks are adequately controlled. Several studies have examined the role of trust in risk perceptions and acceptance of new technologies. (Siegrist, 2021) suggests that trust can be directly linked to risk perceptions, although only in certain situations. That is, "trust seems to be associated with risk perception when people have little knowledge about an issue that is important to them" (p.487).

Slovic, Flynn, Mertz, Poumadère, & Mays, (2000) conducted a comparative international study about risk perception of nuclear power in the US and in France. The study revealed that both country samples had a similar level of concern about the risks from nuclear power and waste, however people in the United States do not support the use of this technology, whereas the French population do. According to this study, results suggest that risk perception was not the factor determining support in France, but instead it was "trust in scientists, industry, and government officials who design, build, operate, and regulate nuclear power" (p.57). In this case, the French sample exhibited higher trust in the risk regulation institutions governing nuclear power use in the country compared to the US sample.

Therefore, previous research shows that regulators that are not trusted could jeopardize the acceptability of a project. Lack of trust in stakeholders may increase public's perception of risks and therefore, decrease the recognition of the benefits, even to a point where the purpose of a technology is no longer acknowledged (Bronfman, Jiménez, Arévalo, & Cifuentes, 2012).

3.4.1 The difference between expert and lay risk perception

Experts have the purpose to examine and develop new concepts, leading to new technological outcomes. These projects, most of the times will be directly or indirectly presented to the general public. Even though, laypeople are considered to be the 'end users', they are mostly not involved until the last stage of a project development.

According to Fiorino (1990) many experts argue that risk decisions should be left to stakeholders with scientific expertise, acting as 'elected representatives' and consulting the public only if necessary. They argue that information surrounding these developments is based on technical data, which might be challenging to understand for the public. Additionally, it is argued that the general public lacks time, information, and inclination to take part in technically based problem solving; "*elites, it is argued, will make more rational decisions*" (p. 227).

This hypothesised interaction between experts and laypeople is based on a one-way 'trust' relationship. There is a pre-define dynamic where the end consumer or general public should accept technical information as true, trusting experts and consequently adopting the technology. Less often, the public is viewed as 'stakeholders' whose involvement in decision-making is seen as leading to better outcomes (Xenias & Whitmarsh, 2018).

This one-way interaction can lead to public opposition of particular developments, such as the examples mentioned earlier about nuclear power or wind farms in the UK. When public is not taken into account at an early stage of a project, the development might be threatened at the last stage. Fiorino (1990) also presents three arguments supporting the involvement of public in the development of new technologies. First, studies reveal that perspectives from members of the general public uncover problems, issues and solutions that sometimes are missed by experts (Pidgeon, 2012). Second, the ‘techno orientation’ standpoint is unethical and should not be allowed in a democratic society, citizens should be able to be part of decisions that affect their community. Third, effective public participation leads to better results, for instance, wider participation may contribute to better decision making and incorporate a larger range of values into decisions.

The inclusion of public perspectives on new technologies is particular important because lay persons and experts often perceive risks very differently. For example, Slovic et al. argues that experts tend to base their risk perception on a hazard analysis and determine level of risk based on the number of fatalities. In contrast, laypeople will take a broader qualitative perspective, taking into account other aspects such as: ‘voluntariness’ – if people have the choice to face the risk , ‘immediacy of effect’ – if the consequence will be immediate or might occur at a later time and ‘catastrophic potential’ – if something happens, whether many people will be killed at once (Marris et al., 1997). As discussed earlier, members of the public are also more likely to rely on their initial affective responses to a technology (unlike experts with technical knowledge).

This comparison of risk perceptions by experts and laypeople suggests that any risk management should account for both ways of viewing risks and aim to be a mutual cooperation between experts and laypeople’s perceptions. The general public should consider the experts’ assessments of risks based on probabilistic assessments and experts should consider perceptions coming from the general public involving cultural and emotional factors (Gorman, 2013). Therefore, it is fundamental, that studies on emerging technologies, like the one presented in this thesis, involve both experts and laypeople perceptions, and compare across these.

When considering differences between public and expert perceptions, it is important to consider who is considered ‘an expert’ vs ‘the public’. Following similar lines as previous work, in this thesis we define experts as those working to develop green ammonia currently (see chapter 5). Given this is the first study on green ammonia, and the technology is only emerging, this ‘expert’ group is quite small and there is no previous research to consult. However, as stated in *Chapter 2,* ammonia is a chemical well known all around the world due to its uses mainly as a fertilizer. Currently it is the second most produced chemical worldwide (The Royal Society, 2020). Therefore, it is useful to briefly review previous studies about risk perception regarding chemicals.

Several studies have been carried out to understand chemicals and the effects on human health throughout risk assessment analysis, however regardless of the efforts of science to present an objective analysis about most of the chemicals we have contact with, the general public may have a different perspective about their risks.

As we mentioned before, people rely on different aspects to create an opinion about a specific risk, and chemicals are no exception. Neil, Malmfors, & Slovic (1994) carried out a study in the US to understand the difference between laypeople and experts regarding risk perception of chemicals.

During the research cited above the objective was to compare and describe the answers between members of the *Society of Toxicology* and members of the general public in Portland, Oregon. They found that laypeople tend to view the risk from chemicals (natural vs synthetic and chemicals in prescription drugs vs chemicals used in pesticides) as either safe or dangerous; while experts, because of their knowledge, were able not to just have a positive or negative answer, but to know in which scenarios will each chemical be better and in what quantities. One of the most interesting parts of this research is the emphasis of the problem regarding risk communication. The research concludes that toxicologists should find new, easier and attractive ways to present their data for the public, taking under consideration subjective elements such as lay perceptions and assumptions about chemicals.

A year later, Slovic et al., (1995) published an extension of this study focused on Canada. After running a similar study with toxicologists and the general public, they reached the same conclusion: the need to find better and clearer ways to present data to laypeople. The study advises toxicologists to acknowledge subjective elements from the general public essential to their analyses, as well as the acknowledgement of the degree of uncertainty in their conclusions. When communicating with the general public, the message must align with their beliefs. Occasionally, experts assess the risk to be small while members of the public have an opposite standpoint and limited knowledge, which will impact on their perspective (Sjöberg, 2007).

These studies show that perceptions of risks associated with chemicals like ammonia can differ between experts (those with scientific and technical knowledge about chemicals) and lay persons (those without technical knowledge). The previous studies also suggest communication and knowledge provision are important for informing people about the risks and uncertainties associated with health risks. While important, however, the field of public understanding of science tells us that simple information provision about, e.g., the toxicology of a chemical, is unlikely to be sufficient to align expert and lay risk perceptions.

The assumption that educating the public about chemicals and their associated risks leads to more acceptance is an example of the *deficit model of public understanding of science*. This knowledge deficit approach assumes that, when necessary, the general public will look for additional information about science topics in order to arrive at an informed and accurate opinion. Therefore, providing more information will make the public more supportive about scientific developments generally (Cacciatore et al., 2012). According to the research cited previously some studies (Thornley & Prins, 2007) have found a positive relationship between public knowledge and support for a number of scientific issues. For example, one study on biofuels found that low levels of support in Europe were linked to low levels of knowledge about alternative energy sources

However, despite the fact that education and information provision might influence public opinion in some cases, most of the studies have shown that the deficit model of public understanding is not completely accurate due to several factors that are not being considered, such as social values, beliefs, and feelings (affective responses). As mentioned in *section 3.4* and pointed out by Renn and Benighaus (2013) individual and social risk perceptions are shaped by different psychological, social, and cultural factors, which exhibits the complexity of understanding how public form an opinion. Knowledge is only one part of it. Despite these new theoretical models to understand public perceptions of low-carbon innovations, as detailed in the above sections, the deficit model for public understanding of science, is still a commonly used one among stakeholders and experts, which is also something we see in the current research (see *Chapter 5*).

3.4.2 Role of public perception in the advancement of hydrogenated vectors

As detailed in *Chapter 2*, the potential of green ammonia relies on its high hydrogen content. Even though, there are limited studies on the topic of ammonia as an energy vector, hydrogen, on the other hand, has been gaining popularity and several public perception studies have been published. Consequently, this section will focus on pointing out the most important findings in different aspects of hydrogen technologies, for example fuel, transport, and infrastructure.

Global awareness around zero-carbon fuels is in line with the concept of a 'hydrogen economy', this refers to "an industrial system in which the dominant role of the energy carrier and fuel is performed by hydrogen together with electricity" (Encyclopaedia of Electrochemical Power Sources, 2009). Is important to note that the hydrogen produced is through carbon free sources and is aimed to deliver a substantial fraction of a nation's energy and services (Ren et al., 2017). Although the technological development has focused on achieving more reliable, efficient and safe hydrogen vectors, views by the public should be taken into account to secure the future of these carbon free alternatives.

As noted in sections above, a popular framework for understanding social acceptance of renewable energy is *The Triangle of Social Acceptance of Renewable Energy Innovation* (see Figure 3.2), this model has been largely employed for analysing acceptance of hydrogen technologies (Gordon et al., 2022). The authors cited previously analysed literature available on this topic and summarised the three main approaches taken to analyse this topic, these are: general attitudinal surveys, non-market economic valuation studies; and risk perception studies (Roche et al. [162]). For hydrogen acceptance literature they highlighted the three elements that most of the research focuses on:

1. Hydrogen for transportation
2. Consumer willingness to pay more to support the introduction of hydrogen technologies
3. Consumer perceptions of risk and safety

Based on the literature research mentioned above, public support for hydrogen technologies seems to be somewhat positive, however it encounters limited awareness and moderate concerns about safety. These studies are mostly based on both assessments of measured knowledge and the effect of information provision. General conclusions from these papers suggest that men, younger people, the highly educated, and those in full-time employment are more likely to be better informed about hydrogen technologies than other socio-demographic groups. “Furthermore, hydrogen acceptance appears to be positively correlated with environmental awareness and trust in technology, while men are typically more supportive than women.” (p.14). Some of the studies analysed are described further below.

Regarding transport, there is a multi-national project entitled ‘AcceptH2’, funded by the European Commission, which aims to understand and measure public perception of hydrogen as a fuel for transport (O’Garra et.al., 2005). As part of this project, several studies have been carried out to understand people’s perception around this topic (Altmann et al., 2004) (Haraldsson et al., 2006), (O’Garra et al., 2005) . Altmann et al. (2004) conducted surveys in five different countries (UK, Germany, Luxemburg, Australia and the US) to explore public responses before and during this hydrogen bus project.

Support for hydrogen and fuel cells was generally high even though the knowledge of these technologies was low. However, there was no opposition for the technology, with more information always requested. Hydrogen was viewed positively when talking about the environment, and negatively when its explosive nature was highlighted. Participants were neutral when presented only with a description of hydrogen’s physical properties. This highlights the importance of considering the way information is presented as it can influence people’s preferences at a given point in time as discussed previously.

Additionally, Hickson, Phillips, & Morales (2007) examined public attitudes from passengers on board buses using hydrogen hybrid internal combustion engines in Winnipeg, Canada. The survey indicated that the acceptance of hydrogen as a fuel was high, with 92% thinking it was a good or a very good idea, choosing hydrogen buses over conventional fossil fuel transport. Positive comments emphasized environmental and energy saving reasons with only 3% of the participants expressing safety concerns.

It was also found, in opposition to the results from Cherryman, King, Hawkes, Dinsdale, & Hawkes (2008) that men tended to support hydrogen more than women.

Flynn et al. (2010) carried out two multi-methodological studies about public perception of hydrogen energy. In the first study, which was conducted through focus groups in England and Wales, people were asked to discuss general aspects of the environment and energy production. After this general discussion, attendees discussed hydrogen in more detail. When hydrogen technologies were explained, participants' reactions were neutral, neither expressing full support nor opposition, pointing out that acceptability of these technologies could only be possible when comparing it with other alternative energy systems in terms of costs, safety and risks. Later, participants expressed the need to examine real demonstration projects to evaluate how well the technology performs in every aspect to fulfil their everyday lives, needs and aspirations. Participants expected these technologies to perform as well as conventional technologies and to provide the same level of comfort and convenience they are used to.

This research group found similar results to the data from (O'Garra et. al., 2005). It was clear from the previous study that participants require further information to make up their minds about hydrogen, especially with regards to criteria such as cost, safety, effectiveness in tackling environmental and energy security problems, performance and convenience. When discussing trust, participants expressed distrust in politicians, industry and businesses to develop and regulate the technology.

The second study was conducted through focus groups and a telephone survey, focusing specifically on hydrogen as a fuel for transport. The most important findings were as follows: *production*: participants debated the use of non-renewable sources to obtain hydrogen, disapproving the use of coal and nuclear power. *Storage*: underground caverns to store hydrogen was an unfamiliar topic to participants. People were curious about the risks from undetected leaks. *Distribution*: participants wanted a cost-effective way of distributing hydrogen while also being safe. *Risks:* participants did not have specific safety concerns about this technology. However, they were interested to know what is expected from them to prevent any potential hydrogen threat

Flynn et al., (2010) concludes 'if we wish to understand why people's capacity and willingness to alter their behaviour and, in this case, to consider adopting an emergent or unknown technology like hydrogen, then we must recognize the importance of the inter-relationship between their experiences and the wider social contexts and processes which influence them' (p.177).

In 2005, Cherryman et al., (2008) explored public attitudes towards the use of hydrogen energy in Wales. Through two focus groups, the researchers found that there were gender differences when accepting a hydrogen technology; in general, women were more positive about this type of technology compared to men. With regards to concerns expressed by participants, safety (use and production) and costs were the most mentioned, emphasizing that the ‘support for this technology’ is dependent on these two factors. Similar results were found in the US by Schmoyer, Truett, & Cooper (2006) where safety was considered the most important aspect, followed by cost and environmental protection (see *Fig. 3.5*).

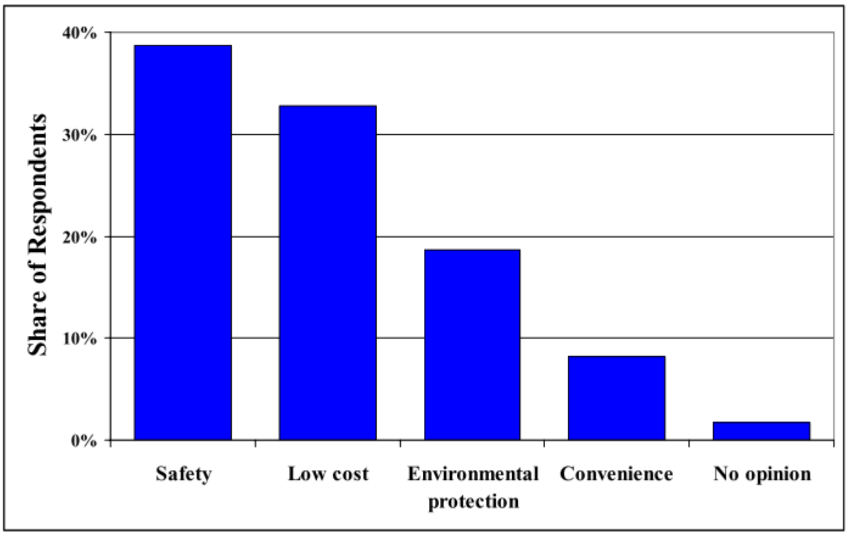

Figure 3.5. Share of general public respondents ranking each factor as most important when all four factors were read. (2007-2017) (Schmoyer et al., 2006)

A current study from the UK Energy Research Centre analysing public perception of hydrogen produced using electrolysis from renewables (Cox & Westlake, 2022) obtained similar results. Cost and safety were the main concerns of participants in the focus groups. Generally, people expressed positive attitudes, reflecting high support for the technology.

In 2010 Sherry-Brenan et al. analysed public attitudes towards the use of hydrogen energy in the UK. The researchers performed a survey based on a social-psychological theory, using a free association method and integrating it into a survey to explore the process of knowledge generated around this type of energy. Results indicated that the largest portion of the sample expressed a low or very low level of knowledge about hydrogen. Nevertheless, they found that there was a positive emotional response to a local hydrogen storage project despite the acknowledged risks posed by hydrogen (explosiveness and flammability) (Sherry-Brennan et al., 2010).

Schönauer & Glanz (2021) carried out research focusing on the public perception of large-scale hydrogen infrastructure in Germany. They concluded that, in general, hydrogen technology obtained positive perceptions in the population, however when referring to large-scale infrastructure in the neighbourhood, the acceptance decreased. This is in line with findings on wind energy discussed previously.

3.4.3 Current public perception of ammonia

Ammonia presents significant advantages over hydrogen such as lower cost per unit of stored energy, higher volumetric energy density, easier handling and distribution, and better commercial viability (see *Chapter 2* for detailed information about ammonia). Due to the importance of understanding public perceptions and in line with the information presented earlier, it is fundamental to examine and understand public views and attitudes towards the use of ammonia as an energy vector at an early stage.

There is however limited research on ammonia as a fuel, nonetheless there is some on the use of ammonia as a chemical and fertiliser. Ammonia has been in the market for hundreds of years and despite the almost null efforts to understand consumers perspectives, there is some research focused on the fatalities of this chemical when not handled properly. It is fundamental to highlight that this might represent a barrier for the technology. The public do not tend to have specific technical knowledge about fuels, and when presented with ammonia as an option they might associate the fatalities caused by the chemical when employed as refrigerant or fertiliser.

For example, *Fig. 3.6* illustrates the number of refrigeration incidents in British Columbia, highlighting the large number of accidents compared with other refrigerants. In the future, studies about public perspectives should also involve communities already in contact with ammonia facilities.

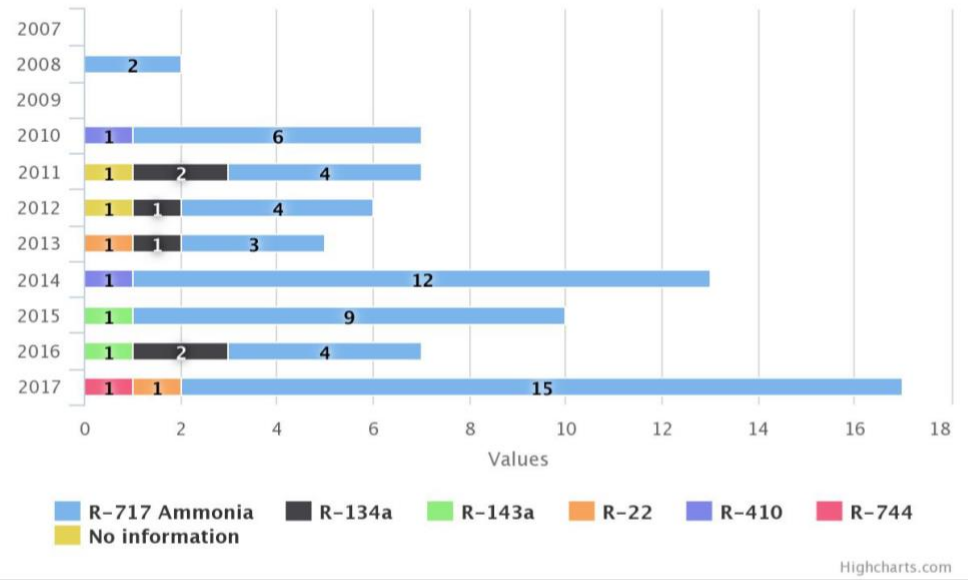

Figure 3.6. Refrigeration incidents by refrigerant in British Columbia, Canada (2007e17).
Safety Authority Vancouver Case Study: Ammonia release incidents (Technical Safety BC, 2018)

One of the most important characteristics of ammonia and a possible future drawback as an energy vector is its penetrating odour. Blanes-Vidal et al. examined the perceived odour annoyance in five Danish nonurban regions. Results suggested that 45% of the respondents were annoyed by odour pollution across their residential areas (Blanes-Vidal et al., 2012).

Green ammonia is a new concept for the industry and formal public perception studies in this field are rare. Brown (Brown, 2012) carried out a small research study in the US to recognize the obstacles for the launch of ammonia as a fuel. He interviewed 26 members of the 'Ammonia Fuel Association' from different backgrounds (academia, public policy development, advocacy, engineers, among others). Results suggest that 41% considered that the technology would be available in between 10 and 20 years but not in the US (53%). According to participants, the three main possible reasons to stop ammonia fuel technology from happening were 'ammonia status- quo' (24%), no government support (21%) and the competition with other fuels (14%), that is natural gas. The research also details the lack of support from the government and highlights the need of the latter to make ammonia fuel possible. Over a third of participants said that the reason for this trend is that NH_3 is not recognized as a fuel yet, which limits the potential of funds and consequently limits demonstrations and development programs (Brown, 2012).

3.5 Climate Change Perceptions

Green ammonia is intrinsically linked to CC because it is being developed as a low-carbon fuel. As it was described in *Chapter 2*, the development of ammonia as a fuel has been gaining popularity due to its zero-carbon properties. Industries and governments have been looking at green ammonia as a promising option to transport hydrogen and achieve climate targets for 2050 (Hayton, 2022). Therefore, to fully understand public perceptions of green ammonia it is important to understand what people believe about CC and how this informs their opinion on ammonia technologies that are presented to them. Additionally, as pointed out in *Chapter 1*, exploring CC perceptions in Mexico is important because of the limited amount of research in the country. Therefore, this thesis provides one of the first explorations of CC perceptions in Mexico.

CC is one of the biggest challenges of the 21st century. Scientists, policy makers and the general public have been working together to look for alternatives to tackle global warming. Despite the large amount of scientific evidence on this topic, there are still a substantial part of the population worldwide who considers CC as a minor threat or not threat at all. According to a global survey conducted by Pew Research Center (2019) from the 26 countries interviewed (see *Fig. 3.7*), a median of 67% considers CC to be a major threat, however a median of 20% think the opposite, considering CC a minor threat, with 9% saying it is *not* a threat at all (Fagan & Huang, 2019).

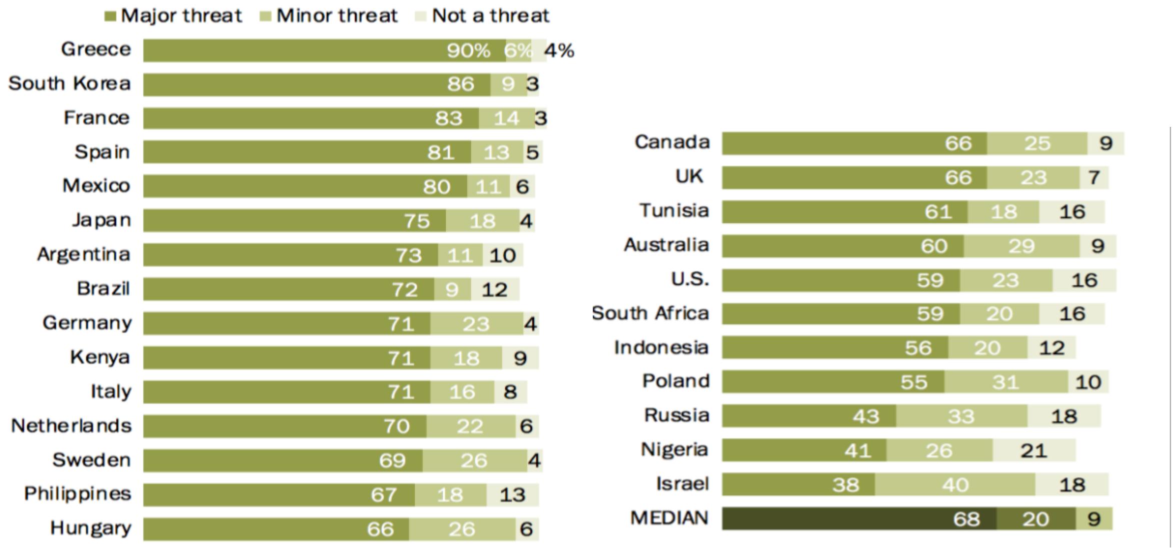

Figure 3.7. In most surveyed countries, majorities see CC as a major threat. Q.21 *Global CC is a ______to your country. Pew Research Centre (2019)*

Additionally, further literature is in line with these results, according to (Poortinga, Whitmarsh, Steg, Böhm & Fisher, 2019) an overwhelming majority of the European population thinks CC is happening and is a major threat.

These results are in line also with data from the RESil RISK project (Steentjes et al., 2020), where it presents that concern about CC has been increasing over the past three years amongst British public "rising to 40% in 2019 compared to 19% in 2016. On the other end of the spectrum, the number of people who are not at all or not very worried about CC has almost halved, with only 20% of respondents opting for this response compared to 38% in 2016" (p.14).

Figure 3.8. Since 2013, concerns about CC have increased in many countries. Q.22 CC is a major threat to our country. Pew Research Center (2019)

An online survey in the UK carried out by (BEIS/DEFRA & Demski, 2021) found that CC scepticism remains very low amongst British public, with the majority assuming a human contribution to CC. According to these results, 83% of British participants were concerned about CC. 14% perceive CC as affecting their local area 'by a great deal' and 86% perceive other countries to be experiencing CC effect to 'at least some extent'.

Even though, data from Pew Research Center (2019) indicates an increase of concerns of CC in Mexico, an analysis performed by Capstick et al., (2015) indicates that this was not the case in previous years. According to the analysis on international trends in public perceptions of climate changes carried out by the authors, from mid 1990s and late 2000s Mexico was showing a decrease in concerns about CC. However, in a study carried out in Mexico City in 2010 by the Universidad Iberoamericana, around 90% of the participants have heard, are worried and understand CC. In addition, 73%-95% agree that CC is mainly caused by humans (Martínez-González, 2010). These results go in line with another study performed in Mexico by Barrera-Hernández et al. (2021) reporting high scored for belief in CC and that humans have a significant effect on this phenomenon.

Even though we can observe a high level of concern about CC around the world (*see Fig. 3.8*) there are other beliefs about CC that may be important to consider – such as knowledge and beliefs about the causes of CC, as well as action on CC in the form of pro-environmental behaviours.

In 2019, González-Hernández, Meijles and Vanclay carried a mixed methodology study in Nuevo Leon, Mexico to analyse perceived barriers to household action to address climate change in Latin American context. The study included an open-ended question CC awareness section, where according to the results participants response to this section reflected a lack of awareness, knowledge, and information. According to the authors participants suggested it was important to address CC but were not sure what measures to take.

3.5.1 Climate Change Knowledge

In order to understand people's concerns and beliefs about CC, is important to explore CC knowledge. However, measuring and analysing knowledge on scientific topics, such as CC is a complex task for researchers. Based on information from (Taddicken, Reif, & Hoppe, 2018) measuring people's level of knowledge about CC must consider clear procedures on *what* to measure and *how*.

Considering the previous study, this thesis has the aim to measure two aspects of general public's CC knowledge: general knowledge and knowledge about energy sources. *General knowledge* was considered fundamental in order to understand the level of baseline knowledge between both countries, mainly due to the limited number of studies on this topic in Mexico. On the other hand, *knowledge about energy sources* was measured with the objective to understand knowledge about the impact of fuels on the environment, due to the low-carbon properties of ammonia as a fuel.

Different studies have been carried out to measure general knowledge regarding CC. An article from the magazine Nature (Nature Climate Change, 2016) states that "awareness of the causes of climate change, rather than its consequences or physical characteristics, can increase the public's concern about global warming" (p.10). However, the article also points out that based on previous studies, knowledge about physical aspects of CC, for example "burning oil produces carbon dioxide" was correlated with a reduction in concern.

Shi, Visschers, Siegrist, & Arvai (2016) carried out a cross-country study on concern and knowledge about CC across six countries: Canada, China, Germany, Switzerland, the UK and the US. The study analysed this topic through an online survey presenting three knowledge scales that addressed three aspects of climate change: physical knowledge, causes knowledge and consequences knowledge.

Results suggest that knowledge is a relevant driver of CC concern. However, different aspects of knowledge play different roles; “Higher levels of knowledge about the causes of climate change were related to a heightened concern. However, higher levels of knowledge about the physical characteristics of climate change had either a negative or no significant effect on concern” (p.761). Scales mentioned previously to measure CC knowledge, were also used to create materials for participants in phase 2.2. in the study presented in this thesis (see *Chapter 7* for detailed information of the scales used).

Given that green ammonia is a technology that presents an opportunity to decrease the use of fossil fuels and consequently help to slowdown global warming, it is also important to understand participants’ knowledge about which fuels contribute to CC. Additionally, it will give us a better understanding of people’s ideas behind the support or opposition for zero-carbon technologies, like green ammonia.

However, knowledge about general aspects of CC or which fuels contribute to global warming, does not necessarily represent acceptance for green energy technologies. A study conducted in Lithuania by (Balžekienė & Budžytė, 2021) revealed that environmental attitudes are significant but not strong factors at influencing public attitudes and perceptions towards energy technologies (see *section 3.4*).

The reason for this is due to the additional elements involved in decision making. The public might be concerned about CC, however factors such as trust, fairness and an overall evaluation of costs, benefits and risks, among others, might play a more significant role for social acceptance of clean energy technologies (Erwin Hofman, 2015). This is the case particularly at a local level (Segreto et al., 2020), green technologies are characterized by high uncertainties, unfamiliar risks, and other characteristics of hazards which make engagement difficult.

Hence, in order to design, implement and generate green technologies with sufficient public support at a national and international level, it is necessary to have a good understanding of the above-mentioned concepts that can inform public perception.

3.5.2 Climate Change and Overpopulation

Overpopulation is a topic often associated with CC, some would describe it as the “root of the problem” (Marx, 2020). The concept was included in this research as a topic because it appeared particularly relevant to Mexican participants in the focus groups (see *Chapter 6*). Given that Mexico City is one of the largest cities in the world, the impact of overpopulation is likely to be more salient and directly affecting Mexicans (The Guardian, 2016).

In contrast, the European Perceptions of Climate Change project (EPCC, 2017) showed that overpopulation is not an issue that British population is concerned about. According to the survey, only 4% of respondents in the UK consider “overpopulation” to be one of the most important issues in the next 20 years. No previous surveys about public perceptions on overpopulation were found in Mexico. Nevertheless, an article from the Universidad Autónoma de México (UNAM) points out that according to official data in 2030 Mexico will be the 9th most populated country in the world (today, 2022, is number 10th) (López, 2018) (World Population Review, 2022).

According to the (Centre for Biological Diversity, 2018) a study in 2009 evaluated the relationship between population growth and global warming, results showed that “the “carbon legacy” of just one child can produce 20 times more greenhouse gas than a person will save by driving a high-mileage car, recycling, using energy-efficient appliances and light bulbs.

It is important to highlight that the study above was carried out in the US. This is important to note because the impact on CC from developed nations is significantly larger than developing countries (Alberro, 2020). According to a report conducted by the Stockholm Environment Institute (SEI) and Oxfam, the richest 10% of the population was responsible for 49% of carbon emissions in 2015, whereas the poorest 50% were responsible for only 7% (Kartha et al., 2020). This shows how higher economic growth is generally associated with higher emissions (Ravallion et al., 2000). This “inequality in emissions” requires to be acknowledged when referring to overpopulation as one of the main causes of climate change.

3.6 Theoretical framework: A exploratory study

Throughout this chapter we have reviewed existing literature relevant for developing the conceptual basis of understanding public perceptions of green ammonia as an emergent technology. This research is an exploratory first study in the area of green ammonia and aims to provide a basis for future research and development of the technology. Therefore, there is not one theory leading the research but instead this study was structured and analysed taking into consideration several concepts and theories as discussed in this chapter (see Figure 3.9 below).

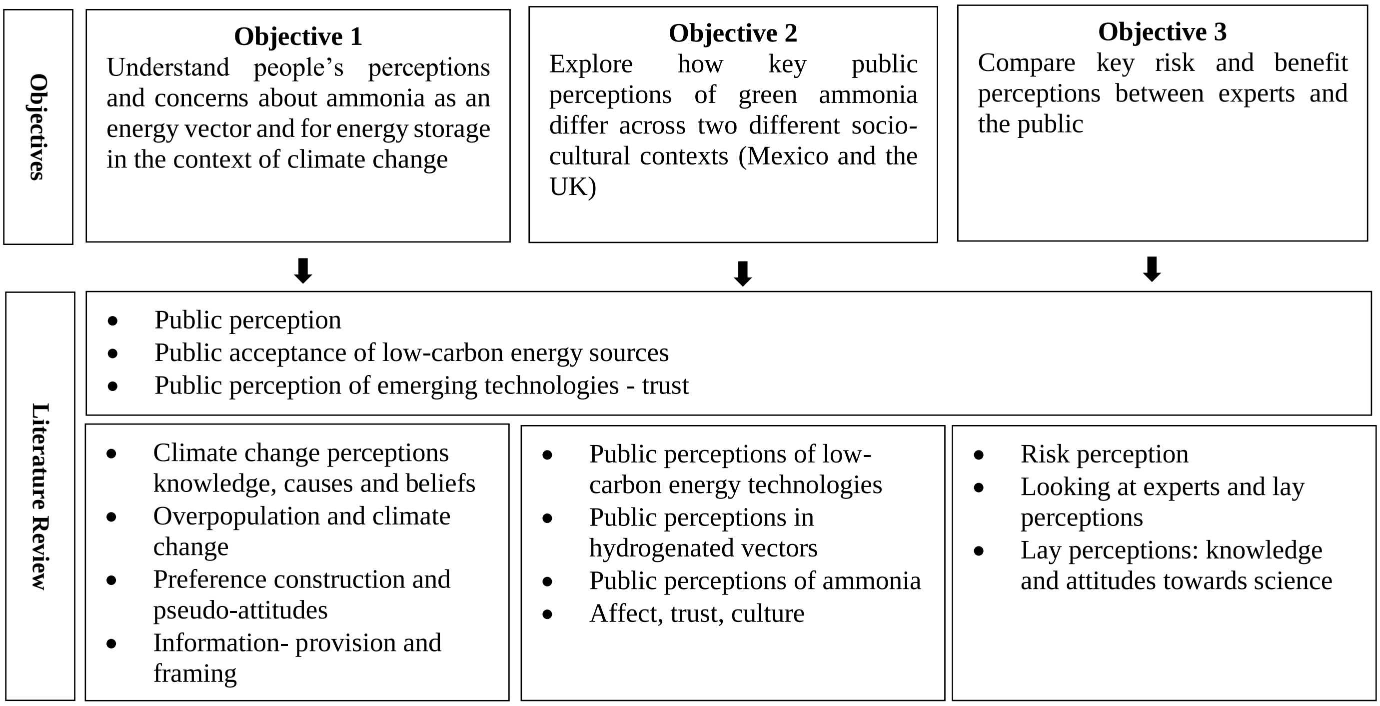

Figure 3.9. Link between the literature review and how it relates to the objectives of this thesis

After providing a literature review about technical aspects of green ammonia in *Chapter* 2, explaining how the green ammonia technology works and its development, this chapter presented the concepts of public perception and risk perception, the basis of our study. Throughout this chapter, these concepts were described, and the first section provided the foundations to understand the importance of developing studies of public perception in emerging technologies, such as green ammonia. Additionally, it highlights the importance of trust as one of the factors that influences acceptability of an emerging technology.

The first objective of the thesis is to **understand people's perceptions and concerns about ammonia as an energy vector and for energy storage in the context of climate change**. In particular, the project examines people's perceptions of the technology and its uses, its governance and societal implications. Green ammonia is intrinsically linked to CC because it is being developed as a low-carbon fuel. Therefore, considering our first aim it is important to understand what people believe about CC and how this informs their opinion on ammonia technologies that are presented to them. Furthermore, as pointed out in *Chapter 1* exploring CC perceptions in Mexico is relevant to the limited amount of research in the country.

In order to design, implement and generate green technologies with sufficient public support at a national and international level such as green ammonia, it is necessary to have a good understanding of the topics surrounding CC public perception. We presented and explained concepts such as CC knowledge, concerns, beliefs and overpopulation.

The second objective is to **explore how key public perceptions of green ammonia differ across two different socio-cultural contexts (Mexico and the UK)**. As noted in section *3.3* several frameworks emphasise the importance of cultural factors, risk perception is not only about the actual experience (or knowledge) about the technology, but also the result of associations and social interaction (Siegrist et al., 2007). For instance, trust has been found to differ across cultures (see section 3.4) which might influence people's perceptions of green ammonia in the two different countries.

Additionally**,** even though, ammonia is a well-known chemical all around the world, the concept of 'green ammonia' as a fuel or as a storage method is a novel idea. Nevertheless, there is research exploring hydrogen systems, which is the main element in ammonia. Therefore, it was fundamental for this objective to present first previous studies on public perceptions of energy technologies, specifically renewable energy. Following by a section on public perception of hydrogen systems. The chapter presents public studies on ammonia as a chemical and one small study in the US as an energy vector only considering experts.

The third objective is to **compare key risk and benefit perceptions between experts and the public**. Information about which specific factors influence public and experts' perception on similar technologies is presented in the third section of this chapter (3.3)

3.7 Summary

This chapter has provided an overview of the conceptual basis for the following chapters. In particular, it has highlighted theoretical issues relevant to the research around public perceptions of ammonia technologies and the importance of integrating experts and lay perceptions.

With the current energy debate around the transition to green alternatives and the efforts focused mainly on a technological development, it is fundamental to understand the social perspective. Therefore, this chapter begins by defining key concepts related to public perception, as beliefs, attitudes, opinions, public acceptance and acceptability. Highlighting the importance of analysing factors linked to public perception and that will be used throughout this thesis to describe how the public perceive or accept certain technologies.

Considering that this research analyses green ammonia as a potential energy system; the following section focused on frameworks to understand public acceptance of low-carbon energy sources. Four main theoretical frameworks (Upham et al., Huijts et al., Boudet & Wustenhagen et al.,) were discussed and considered important to understand how the concepts defined previously play an important role to understand public acceptability of low-carbon technologies. In particular, risk and benefit perceptions, affect and trust appear important for understanding initial attitudes towards low-carbon energy technologies such as green ammonia.

Taking into account the novelty of this technology, the chapter focused on elements related to understanding emerging technologies. Green ammonia as a technology to produce or store energy is only emerging and the public is unlikely to have much familiarity with it. During the data collection process, participants were presented with additional information about the technology, therefore, understanding concepts like preference construction, pseudo-attitudes, information provision and framing were described as important elements to consider when a technology is unfamiliar to participants.

Additionally, the chapter provided literature on risk perception and how it has been theorized and measured. It describes past studies (e.g., Four context levels of risk perception) and frameworks such as the Psychometric Paradigm and Cultural Theory. Additional elements are discussed as important to understand the way people perceive risks and technologies, e.g., affects and trust.

Consequently, this section presented the importance of a joint effort between stakeholders and laypeople when developing new technologies, such as green ammonia. Studies cited in section *3.4.1* show that perceptions of risks associated with chemicals like ammonia can differ between experts (those with scientific and technical knowledge about chemicals) and lay persons (those without technical knowledge). Literature is expanded further and focused of hydrogen and ammonia technologies.

Even though, there are limited studies on the topic of green ammonia, hydrogen, on the other hand, has been gaining popularity and several public perception studies have been published. Hence, this third section focuses on pointing out the most important findings in different aspects of hydrogen technologies, for example fuel, transport, and infrastructure. previous studies about different low-carbon energy systems along with concepts and theories related to public perception. Several examples about the importance of involving the public in the development of energy technologies were presented.

This chapter concludes by presenting CC concern, pointing out the current worry about this topic globally. It indicates that even though an estimate of 67% of the population considers CC to be a major threat, there is still 20% that think the opposite, considering CC a minor threat, with 9% saying it is *not* a threat at all. Environmental concern is significant but not a strong factor at influencing public attitudes and perceptions towards energy technologies. The reason for this is due to the additional elements involved in decision making. The public might be concerned about CC, however factors such as trust, an overall evaluation of costs, benefits and risks, cultural factors (i.e values, religion) among others, might play a more significant role for social acceptance of green energy technologies.

Chapter 4. METHODOLOGY

4.1. Introduction

This chapter describes the methods used to collect and analyse data for this research thesis. The research is divided in two main phases. The first focuses on experts and their perceptions on ammonia technologies (Phase1), and the second on the general public (Phase2). Data was gathered using a multi-methodological approach combining both quantitative and qualitative tools; phase 1 (P.1) involved expert *interviews* and phase 2 consisted of *focus groups (FGs)* (2.1) and *surveys* (P2.2) with members of the public in Mexico and the UK.

The chapter begins by providing a general rationale of the study, focusing on methodological aspects. Consequently, it describes each of the methods utilised (qualitative and quantitative) and explains how these were employed to collect data during the research. Additionally, the importance of applying a mixed methodology approach for analysing public perception is discussed. Following the section of methodological approaches, the chapter included a reflection on researcher bias and positionality regarding data collection and analysis.

It concludes by introducing the concept of cross-national research and presenting the socio-political context of Mexico and the UK during data collection. This chapter provides a general methodological framework for the research. Detailed methodology description of each phase is included in subsequent chapters (*Chapters* 5,6 and 7).

4.2. General rationale and integration of research methods

This research is divided in three stages, each of these stages relate to our research aims. *Figure 4.1* presents a graphic representation of the integration of research methods.

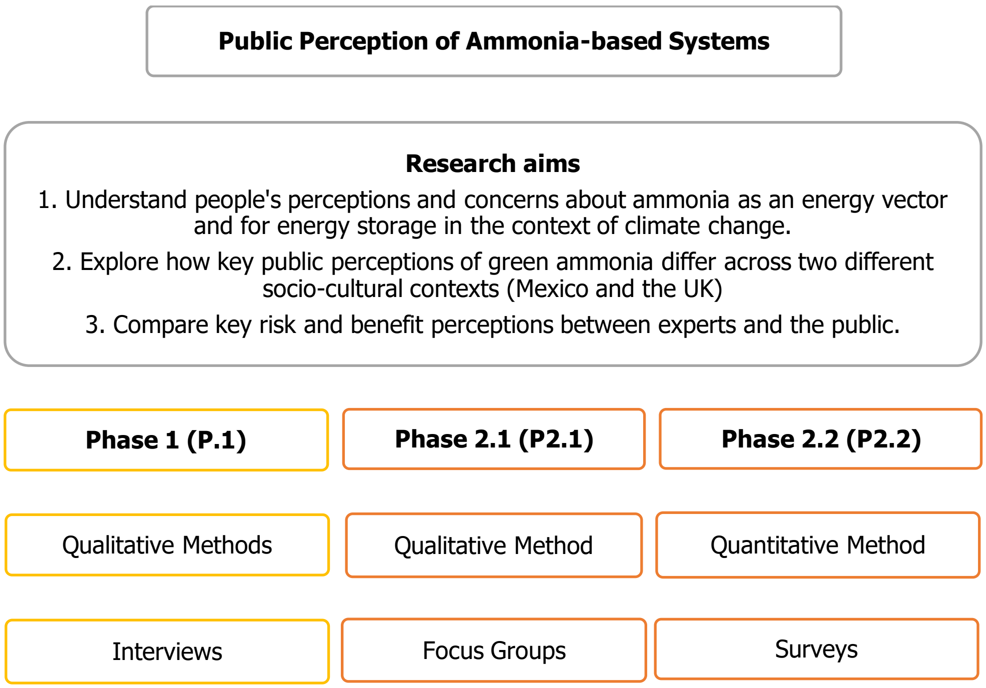

Figure 4.1. Research methodological layout

The thesis employed a pragmatic approach regarding the research methods used. At the beginning of the research, the phases were established along with the methodology for each of them (Alzheimer, 2009). Subsections below will provide a detailed explanation of the rationale behind each methodology.

The use of mixed methods (interviews, FGs and surveys) was thought likely to provide a broad perspective to the examination of public perception of ammonia-based systems. Such a mixed-method approach is recommended (Demski, 2011; Pidgeon et al., 2014) particularly when the socio-technical issues under study are unfamiliar to people, include complexity and uncertainty, and/or have been relatively understudied. Similarly, research carried out in Nigeria to analyse public perceptions of renewable energy technologies highlight the importance of a mixed-methodology approach. The authors stated that it is useful for countries with limited information about public perceptions on a topic to utilise both qualitative and quantitative methods because they enable a richer exploration of perceptions of renewables. As the following sections discuss in more depth, qualitative methods enable a richer picture of perceptions to emerge, whereas quantitative methods enable an evaluation of frequency and diversity in opinions.

The researcher considers that green ammonia will be a new concept for most of the public, therefore using different data collection methods will enable different perspectives to emerge. Specifically, using both qualitative and quantitative data will allow examination of relationships between variables of a wider context (survey) and allow freer expression of opinions and any attitudinal complexities or conditional support (focus groups and interviews).

Even though these two research methods are perceived to be incompatible by many researchers (Sale et al., 2002), by combining both quantitative and qualitative tools we were able carry out different levels of social research and obtaining a more robust understanding of public attitudes and risk perceptions towards ammonia technologies and the social context in which they are being developed. According to Geddes (2021) a combination of qualitative and quantitative methods can provide a better understanding when analysing the adoption of renewable energy technologies as it provides good coverage of different perspectives.

4.3. Qualitative Approach

Qualitative research is usually associated with the *constructivist* epistemology, this approach affirms that there are multiple realities or 'multiple truths', based on one's construction of reality. This reality is socially constructed, therefore is constantly changing (Berger & Luckerman, 1967). This approach tends to be inductive and more concerned with the generation of theories than with testing them (Dowler, Green, Bauer & Gasperoni, 2006).

Considering the previous statement, when conducting a qualitative study, research questions cannot be unquestionably established. This methodology emphasis is on the process and meanings. The research has a clear problem or topic; however, the research questions need to be flexible enough to evolve and change as the study progresses or if needed (Maxwell, 2003). In this type of research, it is important to obtain the perception of diverse people, providing information about the background of the participants and the context in which they are being studied (Hudson, 1954). Thus employing a qualitative approach enables a deeper understanding of public perceptions of green ammonia to emerge.

Qualitative research is appropriate for exploring ideas, beliefs, emotions, and behaviours that exist in relation to a particular issue. The techniques used in this type of methodology include interviews, FGs, participant observation, amongst others. Samples are not meant to represent large populations. On the contrary, it tends to obtain data from small group of respondents that could potentially provide important information about a topic (Vishnevsky & Beanlands, 2004). Researchers using such methodologies intend to gain an understanding of people's experience and perception and not information that can be generalized to larger groups.

Qualitative approaches have become a popular tool to analyse emerging technologies. For example, Jones et al. (2017) carried out a study about lay perceptions of Carbon Dioxide Utilisation technologies in the UK and Germany. The authors utilised an individual qualitative interviewing technique as their methodological approach, according to the authors "qualitative interviewing offers a means of providing an in-depth, discursive forum for exploratory research" p.285. As it was mentioned in Chapter 3 and highlighted also by the authors in this research, qualitative methodologies are often utilised to reduce the possibility of obtaining pseudo-opinions and enables freer expression of people's impressions of technologies (e.g. initial risk perceptions and associated affect). Additionally, they point out that this approach has been successfully employed to analyse expert and lay opinions of a number of emerging technologies, such as CCS, geoengineering, hydro energy technology and hydraulic Fracturing (Wallquist et al., 2009; Pidgeon et al., 2012; Ricci et. al. 208; Ladd 2013).

In this research we utilised two different qualitative tools: *semi-structured interviews* and *FGs* for understanding perceptions of two different actors: experts involved in the development of green ammonia and laypeople who do not have prior experience with ammonia energy systems.

One qualitative method used in the current research is that of semi-structured interviews (with experts). There are three common types of interviews: unstructured, semi-structured and structured. Semi-structured interviews, as the name indicates, is in between and employs a combination of unstructured and structured questions, accompanied by follow-up prompts (e.g. why or how questions). This type of interview is similar to a conversation; the researcher has clear topics and few structured questions (typically five to eight broad questions) but also connection words to link different topics (Adams, 2015). The order of the topics in a given interview may vary but all the topics are address by the researcher with all the participants. The aim of performing semi-structured interviews is to allow participants to engage in the topic and express their opinion and possibly discover unforeseen issues or topics related to the research without being restricted to specific questions pre-established by the researcher (Marks & Yardley, 2003).

The research also employs FGs as another form of qualitative methods. FGs typically include a group of people who are being asked about their perceptions, opinions, beliefs and attitudes towards a certain topic (Morgan, 2012). Similar to semi-structured interviews, the researcher prepares topics and a protocol with follow-up questions, where participants are asked about certain topics. Here the researcher uses group interactions as part of the method and people are encouraged to give their opinion and reply to other participant's point of view (Kitzinger, 1995). The aim of FGs is to understand participant's perception of a certain topic in a social environment and how this influences their beliefs and opinions (Gibbs, 1997).

Qualitative methods, such as the ones mentioned previously, are useful to explore a range of beliefs and opinions that exist in relation to a particular issue. However, there are also some limitations that need to be address. One of the main disadvantages of qualitative methods is that they do not provide statistically representative findings that can be generalised to the wider population. Similarly, relationships between different types of viewpoints, e.g., socio-demographic factors, are difficult to determine. Additionally, it can be influenced by researcher bias, which involves unintended errors in the research process attributable to a researcher's preconceived beliefs (APA, 2018). Therefore, controls must be part of the data collection process (Gaille, 2018) such as creating a research plan or considering having multiple people on a research team to evaluate data (Indeed, 2021).

4.3.1 Qualitative research in this thesis

A qualitative research approach was selected as appropriate for the aims of the first two studies in this thesis, which focused on the perceptions of experts and those of laypeople. Findings from this phase were used to create information materials to be presented to people in the second stage of the project using a quantitative approach.

4.3.1.1 Semi-structured interviews with experts (Phase 1)

A set of eleven semi-structured interviews with experts were carried out to (1) gain a better understanding of why ammonia energy technologies are being developed and how these are envisaged to be part of a future energy system. Findings from this phase will also be used to create materials for presentation to public participants in phase 2 of the research. (2) To understand key risk and benefit perceptions of green ammonia among those involved in its development (for comparison with public perceptions). (3) To understand whether and how experts involved in the development of green ammonia perceive public perceptions to be an important aspect of technology development.

The aims of the research phase were exploratory but with specific questions in mind – taking this from the risk perception literature (e.g. what experts perceive the risks and benefits to be, views on the relevance of public perceptions). Therefore, semi-structured interviews were chosen because it enables an exploration of these theoretically important questions, but also enables a freer expression of opinion so the experts can bring up any new topics that they think are important in relation to development of green ammonia.

The study analysed in detail the perspective of experts highlighting the reasons why they are currently working with ammonia (or renewable energy technologies), as well as their opinion about the role of the general public in the development of new technologies. After understanding the reasons why experts are working with ammonia-based systems, the research examined perceptions of advantages and disadvantages of the technology, as well as concerns, benefits and risks. Followed by the perceived role of laypeople, perception of costs and opinion about using ammonia to store excess energy from renewables. The detailed methodology for interviews (*P1.1*) can be found in *Chapter 5*.

Findings from this phase were used to create information materials to be presented to people in the second phase of the project (*P2.1 and P2.2*). In addition, expert risk and benefit perceptions for future ammonia energy technologies were compared to public perceptions to highlight any risks or other potentially contentious issues (see *Chapter 8*).

4.3.1.2 Focus Groups (Phase 2.1)

After concluding the first phase with experts in ammonia technologies, we created the interview protocol for the second part of the research with laypeople taking into account the results obtained previously. For P2.1 four FGs were carried out in Mexico.

Due to the novelty of the topic, and the exploratory nature of the research, a qualitative method was chosen because it enables participants to express their ideas without being restricted to a specific answer established by the researcher, like in the case of questionnaires. Focus groups also enable exchanges between participants, which may provide a richer picture of their perceptions, and attitudes because they are able to enter into longer discussions about a topic (rather than a question answer exchange as is often the case in interviews). The focus groups were designed around a set of open questions to encourage participant discussion on a set of topics in relation to climate change and ammonia. The beginning of the focus group was designed to capture people's initial associations and impressions of ammonia without any information being provided by the researcher. Later in the focus group, information about green ammonia was provided to participants who were then encouraged to discuss their reactions to this information.

Qualitative methods such as this took place in the study to obtain a general idea of the perception of renewable energy and ammonia. The purpose of using this type of methodology is to gain appreciation of how people's socio-cultural context (in this case in the country context of Mexico) shape their perception about a specific element: their different point of views towards different circumstances (Marks & Yardley, 2003). The detailed methodology for FGs (P2.1) can be found in *Chapter 6*.

4.4 Reflection on researcher bias and positionality

It is recognised that the researcher is an active agent in choices about data collection and analysis, and that they bring existing assumptions and experiences which may influence these (Bryman, 2004). It is therefore important to be clear about these and how they may influence the outcomes of this research. In the following paragraphs I reflect on my motivation for carrying out the research, to be as transparent as possible about this.

My motivation for carrying out this research is understanding how people may react to and understand ammonia technologies in the context of using these to find solutions for climate change (e.g. by storing excess energy from renewable energy). As such, methodological choices were made to frame ammonia technologies in the context of climate change, in part, also because I believe these technologies would not be developed if we did not have climate change as a problem to solve. Having had a background in technical analysis of energy technologies, I was particularly interested to understand the social aspects of technology design and acceptance, but I acknowledge that I have an existing positive bias towards the technology.
Nonetheless, I do not believe ammonia technologies should be developed without taking concerns from the population into consideration, and I feel this aspect is often not considered until the technologies are ready for implementation. This realisation comes from working with technical engineers in academia as well as in communications in large corporations. Therefore, I am motivated to explore public concerns and perceptions at an early stage of the technology to build better understanding and awareness of how these could be integrated into technology design and development.

I also acknowledge that I am a Mexican researcher based in the UK, which gives me an advantage in understanding the Mexican political and social context, which undoubtedly influenced by facilitation and interpretation of the focus groups. Nonetheless, I am not currently based in Mexico, which means I may not be as embedded as the focus group participants. Wherever possible, I have discussed limitations in this regard. Similarly, my background in technical analysis and communication has likely influenced by methodological choices (e.g., wanting to gather both qualitative rich and statistical data to explore public perceptions), but I acknowledge there are other approaches and interpretations that could have taken the research into a different direction. I attempt to be as transparent as possible about my choices and interpretations in the following chapters. Alternative approaches and research questions, important for future research, are discussed in the last chapter.

4.5 Quantitative Approach

Quantitative research is based on a *positivist* epistemology, this relies in the belief that "there is only one truth", one objective reality (Hudson, 1954). In this approach, the researcher and participants are independent entities and do not influence or are not influenced by the data. The aim with this type of methodology is to "measure and analyse causal relationships between variables within a value-free framework" (Denzin and Lincoln, 1994 as cited in, (Sale et al., 2002, p.44).

In comparison to qualitative methods, quantitative offers specific and numerical results. It has a deductive orientation, applying objective and value-free methods commonly used to the study of social realities (Dowler, Green, et al., 2006). The clearest difference between quantitative and qualitative methodologies is that quantitative methodology is constructed as a research strategy that emphasizes quantification of data while qualitative emphasizes in the analysis of words rather than numbers (Bryman, 2012).

Sample sizes in this approach are larger than qualitative methods to obtain views from across a population; ideally samples are representative of that population so findings can be generalised. Quantitative methodologies also enable statistical analysis of perceptions and attitudes and enable an analysis of relationships between variables.

For this study we utilised survey methods to analyse public perceptions of green ammonia in the UK and Mexico. The main advantage of this type of methodology is the *accuracy*, it is based on data and measurements, therefore it provides numerical results that can be statistically analysed and replicated (Profillidis & Botzoris, 2019). Additionally, as mentioned previously, it allows the researcher to obtain data from a larger number of participants compared to qualitative tools, which provides the opportunity to generalize the results to the population from which the sample was drawn (Anderson, 2010). Surveys of public perceptions, like the one used in this research, are useful to obtain a quick answer to straightforward questions. The questions are designed in a way that answers can be easily categorized and quantified. By standardizing the procedures through which perceptions are measured, we reduce bias and produce valid and replicable results that can be generalized (Dowler et al., 2006).

However, this type of methodology also encompasses some limitations. It restricts participants to a certain number of possible responses, limiting the understanding of people's perceptions and attitudes. Additionally, it does not provide context, so it is difficult to understand the whole perspective of a phenomenon. For this reason, findings from both the quantitative and qualitative phases of research as combined to create a richer picture of public perceptions of green ammonia. This is discussed in more detail later in this chapter.

4.5.1 Quantitative research in this thesis- Survey

Once a general perspective about experts' and laypeople perception, renewables and ammonia was obtained with the interviews and FGs, a quantitative study took place. Through this phase we aim to (1) examine public responses, perceptions and understanding of ammonia in a larger, more representative sample. (2) Compare key perceptions across Mexico and the UK to gain a better understanding how the national and socio-cultural context may shape views. (3) Explore how socio-demographic factors and climate change perceptions relate to public support for green ammonia technologies

The questionnaire was distributed through online surveys in Mexico and the UK. The use of a survey to measure public perceptions of ammonia enables capturing perceptions from a wider and broader population sample than was possible with focus groups. Ideally the samples would be representative of the country population so generalisations can be made about how prevalent different perceptions and responses to green ammonia are. This can however be difficult to achieve if resources are limited as was the case for this thesis. While this thesis was not able to sample a fully representative sample for the populations in question, it still enables reaching a wider set of participants and can still say something about how widespread views are among the types of populations captured (a discussion of the samples and how they are and aren't representative of the wider population is included in *Chapter 7* covering the survey findings and further discussed in the final chapter).

Furthermore, a survey was chosen because it enables an exploratory examination of the relationship between different perceptions and attitudes – for example the role climate change perceptions play in explaining support for green ammonia. Methodological details about the surveys (P2.2) can be also found in *Chapter 7*.

4.6 Mixed Methods

Both quantitative and qualitative methods provide individual benefits as outlined previously. However, when used together, we are able to gain a deeper and richer understanding of perceptions of green ammonia (Bryman, 2006). Using only one methodology might restrict findings due to the limitations of that method (Slovic, 2010).

As shown in Figure 4.1, a mixed method, also referred to as multi-strategy or multi-method approach, was selected and considered appropriate to address the research aims. Although, numerous authors (Creswell, 2014) (Bryman, 2006) promote the use of a multi-methodological approach, a debate about the use of multi–methodological research is still going on.

Those in favour of combining methods state that a multi methodological research could enhance the outcomes of research and provide more comprehensive and reliable findings. Authors against the combination of both quantitative and qualitative methods are of the view that is impossible to combine these approaches due to their different epistemological and ontological foundations (*constructivism* vs *positivism*) (Bryman, 2012). This thesis aligns itself with the former view and takes on a pragmatic epistemological approach, which suggests that there are different ways of understanding the same topic. Each methodology used in this thesis is considered to provide different tools for exploring and understanding perceptions of green ammonia; with no single methods being able to provide absolute reliability and accuracy (Henwood & Pidgeon, 1992).

4.6.1 Mixed methodology in this thesis

Throughout this chapter we have explained the epistemological differences between the data collection methods utilised in this research. However, we have also made evident the benefits of combining these tools in a public perception study such as the one conducted in this thesis. Because ammonia is an emerging technology and very little is known about expert and public perceptions, a mixed methodological approach was used for complementary purposes. Interviews and FGs provided a way to examine ammonia with experts and laypeople in a more exploratory and in-depth way. This provides an initial analysis of key topics relevant to perceptions of ammonia. The quantitative survey then enables a broader population to be reached and key perceptions to be tested across a wider sample. Combining both quantitative and qualitative tools, we were able carry out different levels of social research and obtain a more robust understanding about public attitudes towards ammonia and the context in which perceptions are constructed.

The approach in this thesis is to combine quantitative and qualitative methodologies, but not to fully integrate them. Indeed, the different methods are used in a complementary and sequential way. This means that each research phase in the thesis (*P.1*: interviews, *P2.1:* focus groups and *P2.2:* surveys), is used to provide unique insights into perceptions of green ammonia and this findings from each phase are first explored separately (*Chapter 5*: interviews, *Chapter 6*: focus groups and *Chapter 7*: surveys). The phases also build on each other, whereby findings from the expert interviews are used to develop the focus group protocol in phase 2 and the survey questionnaire is constructed, in part, using findings from the FG (as well as theory). Finally, the findings from each research phases are also compared and combined to provide further insights in line with overarching objectives of this thesis. As such, public perceptions of green ammonia will be analysed by combining insights from the focus groups and the surveys, also considering the country context in which each dataset was collected. Perceptions from experts and laypeople will also be compared, highlighting similarities and differences regarding the perception of green ammonia technologies.

4.7 From concepts to practice: developing cross-national research

Culture represents an important role in people's lives; it comprises of the social behaviour and norms found in human societies, as well as their attitudes and thoughts (Ilesanmi, 2009). Research on environmental psychology suggests that risk perception is specific to culture and place (Taylor et al., 2014).

Based on the cultural theory of risk, the impact of culture on people choices – what societies choose to call risky– is determined not by nature but by social and cultural factors (Breakwell, 2014). Therefore, in order to take appropriate adaptive measures regarding concerns from public we must recognise and analyse the role of the embedded culture. According to Taylor et. al (2014) several cross-country comparisons about CC have demonstrated clear differences in people's beliefs and conceptualisation, for example in regard to perceptions of threat and support for adaptation policies. For example, studies have shown that the British population is less worried about climate change and less likely to believe that climate change is the result of human activity, when compared to Italy, Spain and France (Lorenzoni and Pidgeon, 2006 as cited in

(Taylor et al., 2014). These results highlight the importance of understanding collective ideas but also to be aware of regional differences in perceptions of CC and its impacts.

Cross-national research could be understood in general terms as a comparison between two or more cultures or nations. Throughout this research we will understand it as comparative research that involves political, economic and social structures. “One or two societies, cultures or countries are compared in respect of the same concepts concerning the systematic analysis of phenomena, usually with the intention of explaining them and generalising from them” (Simpson et al., 2016)

Many declare that this type of studies provides robust information that allows researchers to contrast and compare cultures, understanding why a variation exists (if any) (Momir et al., 2015), (Escotet, 2021), (Papayiannis & Anastassiou-Hadjicharalambous, 2011). The expansion of energy technologies implies an inevitable transformation of the physical space where the technology is being developed, which translates to a direct impact to the community. Therefore, this illustrates the need to understand public perception of different energy systems and how these opinions might differ from one community to another (Ekins, 2004).

Notwithstanding the positive factors that cross-national studies provide at analysing public perceptions it is also accompanied by certain limitations. Collecting data in two or more countries, apart from being costly in terms of time and money, can represent a lot of challenges. According to (Boholm, 1998) in cross-national studies the methodology and the design of all the instruments should be chosen carefully, considering the nature of this type of research. Otherwise, methodological inconsistencies may arise and provide contrasting results due to the design of the measures, rather than from the actual differences between cultures. It is essential that the study is designed based on comparative purposes, taking into consideration theoretical concepts, comparisons, definitions and of course scales adopted for measurement must be equivalent between one nation and another. Consequently, Bolhom also states that once the methodological considerations of a cross-national study are met, then it is important to consider the interpretation of the results and take into account the embedded differences of each culture. The limitations in this study based on cross-national research are discussed in *Chapter 8*.

4.6.1 Social and Political research context

This project was carried out across Mexico and the UK, providing an opportunity to examine potential deployment of ammonia projects in two different countries and analysing similarities and differences, as well as their drivers, in public perceptions across two different contexts.

As discussed in *Chapter 1*, each of the countries was chosen for specific reasons. However, when interpreting the research results, it is important to take account of the immediate socio-political and environmental context that preceded it. Data was collected between June-July 2019 for the FGs in Mexico and between May 2020 - June 2020 for the survey distribution in the UK and Mexico. Both time periods came during a number of prominent events in each country that may have impacted public perception of CC and green ammonia. The following sections provide further context for each country.

General research Context

Data collection for surveys in Mexico and the UK (Phase 2: Part 2) took place between May and June 2020. During this year, a significant event took place: the covid-19 pandemic. At the end of January 2020, the World Health Organisation (WHO) declared a global health emergency. The UK confirmed the first case of Covid-19 in the country in January 2021, followed by a national lockdown in England, Wales, Scotland, and Northern Ireland (Aspinall, 2021). After 5 months of lockdown, at the time the survey was distributed (May and June), the UK Prime Minister announced plans for the easing of lockdown

However, in Mexico, at the end of January the government stated it was not going to represent a danger to Mexico and lockdown was not enforced. It was not until the beginning of May when the Mexican government announced a "voluntary" lockdown, it was advised but without repercussions such as curfews, arrests or fines were in place (Sheridan, 2021). This indicates that during the survey not all Mexican participants were in lockdown or were even aware of the impact of the pandemic, which is different to the situation in the UK.

Because data collection for the surveys occurred right at the start of the pandemic and was on an unrelated topic, it is however unlikely that it had substantial effects on people's perceptions of energy and ammonia technologies or climate change.

4.6.1.1 Mexico

Country Overview

Mexico (officially the United Mexican States) is a federal republic divided into 32 states. It is the 15th largest economy in the world and the second-largest economy in Latin America, after Brazil (Teresa Romero, 2021). It holds a population of approximately 126.19 million habitants (The World Bank, 2019a), Mexico City being one of the largest cities in the word with almost 20% of the entire population of the country residing here. In 2018, the left-wing former mayor of Mexico City, Andres Manuel López Obrador (known by his initials AMLO), won an overwhelming victory in the national presidential elections.

The national newspaper *El Financiero* (Usla, 2019) citing data from the National Institute of Statistics and Geography (INEGI), stated that Mexico reached an average educational level of first year of high school (2018), meaning that most students leave school at around 16 years old. In the same line, the newspaper *Sin Embargo* reported that 29.5% of the total population in Mexico has a degree equivalent to a GCSE O-level (Redacción, 2018).

According to official data, there is only a 3.1% rate of unemployment in the country (Información Dinámica de Consulta, 2020). However, 56.1% of those in full-time employment is under a scheme called "informal working status" (INEGI, 2020) which refers to "any work that is done without having the protection of the legal or institutional framework" (OIT Oficina Regional para América Latina y el Caribe, 2007); Only 4 out of 10 Mexicans hold a formal full-time employment contract (Valadez, 2019).

Energy Sector

Concerning the energy sector, Mexico is one of the largest oil producers in the world (EIA, 2021) and contains one of the largest proven natural gas reserves. Mexico's economy heavily relies in the oil and gas industry, contributing to 28%-38% of Mexico's GDP, the second source of income of the country.

Oil and gas in the country are the main energy source in the country as shown in Figure 4.3. According to the (U.S. Energy Information Administration (EIA), 2021) the Mexican government projects consumption of natural gas to increase 30% from 2017 to 2032 and most of this consumption to be from the electricity sector, also dominated by natural gas representing 66% of the market (Frontline World, 2005) (see Figure 4.2).

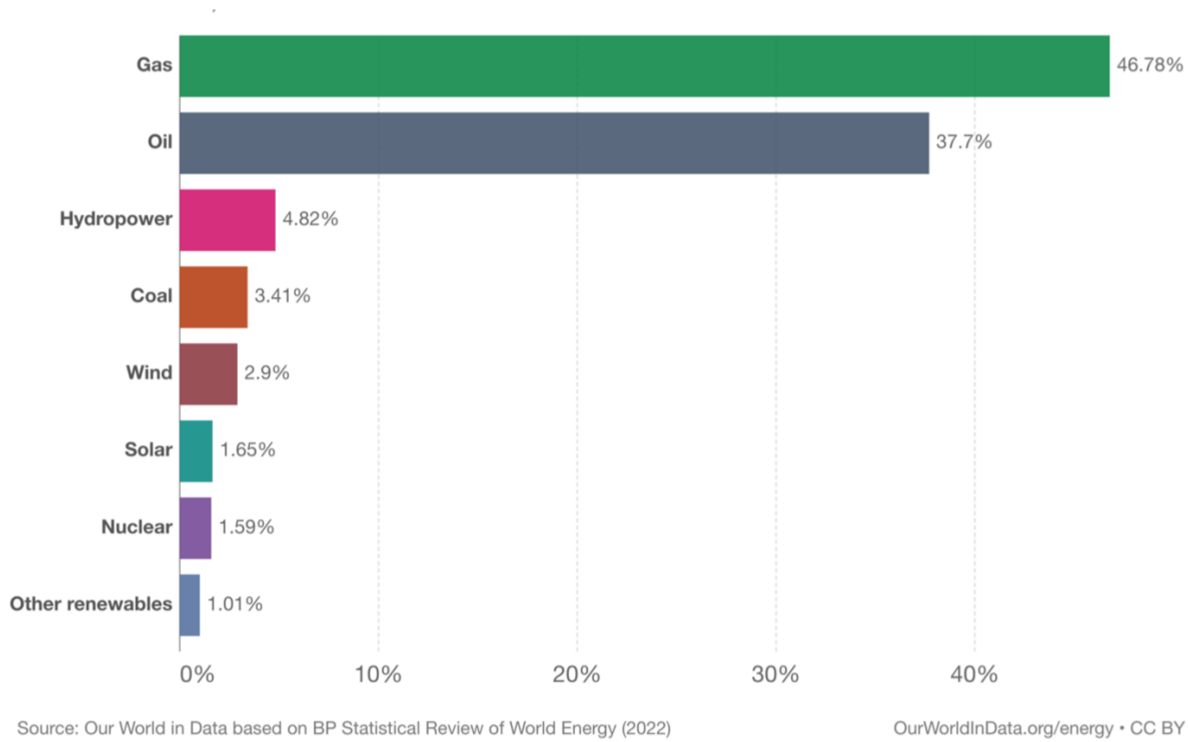

Figure 4.2 Share of energy consumption by source, Mexico 2021 (Panos et al., 2020)

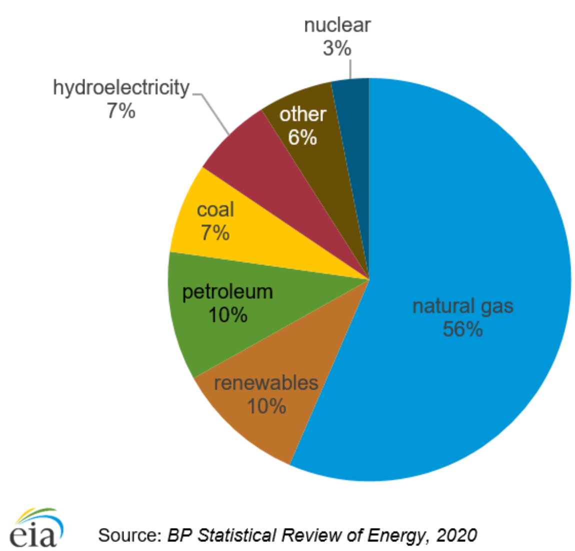

Figure 4.3. Electricity generation by fuel in Mexico, 2019
(U.S. Energy Information Administration (EIA), 2021)

Even though the country has one of the largest proven natural gas reserves in the world it does not have the resources to exploit its deep-water crude reserves and imports the gas from on the U.S. (Clemente, 2019).

In 2019 Mexico imported approximately 5.5 billion cubic feet per day from the U.S. (by truck, by pipeline, and as LNG) “an increase of 176% from 2014” (EIA, 2020).

Additionally, Mexico owns one nuclear plant located in Veracruz (eastern Mexico) operated by CFE and responsible for 3% of Mexico’s total electricity generation in 2021 (Clemente, 2019). The plant includes two boiling water reactors. In order to reduce natural gas consumption in the country, in 2019 the CFE announced the expansion of Mexico’s nuclear generation capacity by building four new nuclear reactors (World Nuclear Association, 2022) (Panos et al., 2020).

Currently, the energy sector in this country is a complex and controversial topic, which might influence the perception of participants when asked about fuels, emerging technologies and trust in institutions.

For more than 73 years, every aspect related to energy was controlled and produced by the national oil company, Mexican Petroleum (PEMEX). In the case of electricity, the Federal Electricity Commission (CFE) was in charge to generate, lead, transform, distribute, and supply energy for the provision of public service. In 2013, with the former president, Enrique Peña Nieto, a new energetic reform was born, presenting significant changes in the regulation of hydrocarbons, electricity and fertilizers among others - thus allowing foreign investment in the development of energy technologies and boosting renewable energy (Sheky, 2021).

Two years into the administration of the current president, AMLO, the energy sector has been completely transformed again; placing the state oil company Pemex and CFE at the core of the political agenda. In 2019, the government approved the development of 20 new priority fields to be developed by PEMEX as a business strategy to encourage oil production (Sheky, 2021).

Usually, left leaning governments will lean towards environmental values but this is not the case for AMLO. He cancelled planned energy auctions for renewable energy projects upon entering office. Additionally, between 2018-2021 he cut the budget of the Energy Regulatory Commission (CRE) in charge of new green technologies by 70% (Arnold-Parra, 2021). Since April 2020, the government has denied 40 wind and solar power plants to connect to the national grid, arguing that the pandemic required an uninterrupted power supply (Fernandez, 2020).

According to data from November 2020, the largest renewable power generation in Mexico is hydroelectric power. In 2019 hydroelectric accounted for 39% of all renewable generation. Other sources such as wind, solar and geothermal represented only 6% (EIA, 2021).

During data collection in this country two important factors took place:

1. Announcement of new oil refineries
2. Extreme weather patterns reported in Cancun

The FGs were carried out in Mexico City and Cancun. During data collection there was a complex political panorama in the country. As mentioned previously, it was a year with a lot of transformations on account of the new presidency of AMLO.

One month before the FGs the investment for the 20 new oil refineries was announced along with the statement that renewable energy was not going to be a priority for the government in the next 6 years (term length) (Expansion, 2019). During this time people reported to feel uncertain about the future of the country's economy and the path of the energy sector (Lafuente, 2019).

At the same time, extreme weather patterns were reported in Cancun during the months of data collection. On one hand, heavy rain was paralysing the streets of this city and, on the other hand, a heat wave, with temperatures above 40ºC, was reported. The local government recommended people to stay home (Riviera Maya News, 2019), which limited the arranged FGs in this region. In the end, one of the FGs had to be relocated to Mexico City for this reason.

4.6.1.2 United Kingdom

Country Overview

The UK consists of four countries: England, Wales, Scotland and Northern Ireland. The government system is a constitutional monarchy and a Commonwealth realm; the chief of state is Her Majesty Queen Elizabeth II, and the head of government is the Prime Minister. During data collection, Boris Johnson was the PM elected, leader of the Conservative Party (BBC, 2020).

The UK has a population of 66.8 million people (2020) and is the sixth-largest economy in the world (Nordea Trade Portal, 2021). According to the Office for National Statistics (ONS), 42.2% of the population hold a first-degree qualification from which 22% have a taught master's degree (ONS, 2017). In 2019, the UK reported 76.1% of people in full-time employment (Office for National Statistics, 2020).

Energy Sector

The energy sector in the UK is a key component for the country's economy. In 2019, the energy sector created £30.9bn in gross value added, the second largest sector only after telecommunications (Energy UK, 2021). Of the total energy outlook, oil and gas extraction accounted for 29%, electricity (including renewables) 46%, and gas accounted for 17% (Department of Business Energy & Industrial Strategy, 2020).

Regarding total energy consumption, data from the International Energy Agency in 2021 affirms that the main source was natural gas with 38.58%, oil 34.76%, renewables (wind, solar, hydropower and others) 17.14%, nuclear 5.78% and coal 2.93% (see Figure 4.4). If we look at the sectors, currently (2022) domestic and transport are the sectors with a largest energy consumption (see Figure 4.5).

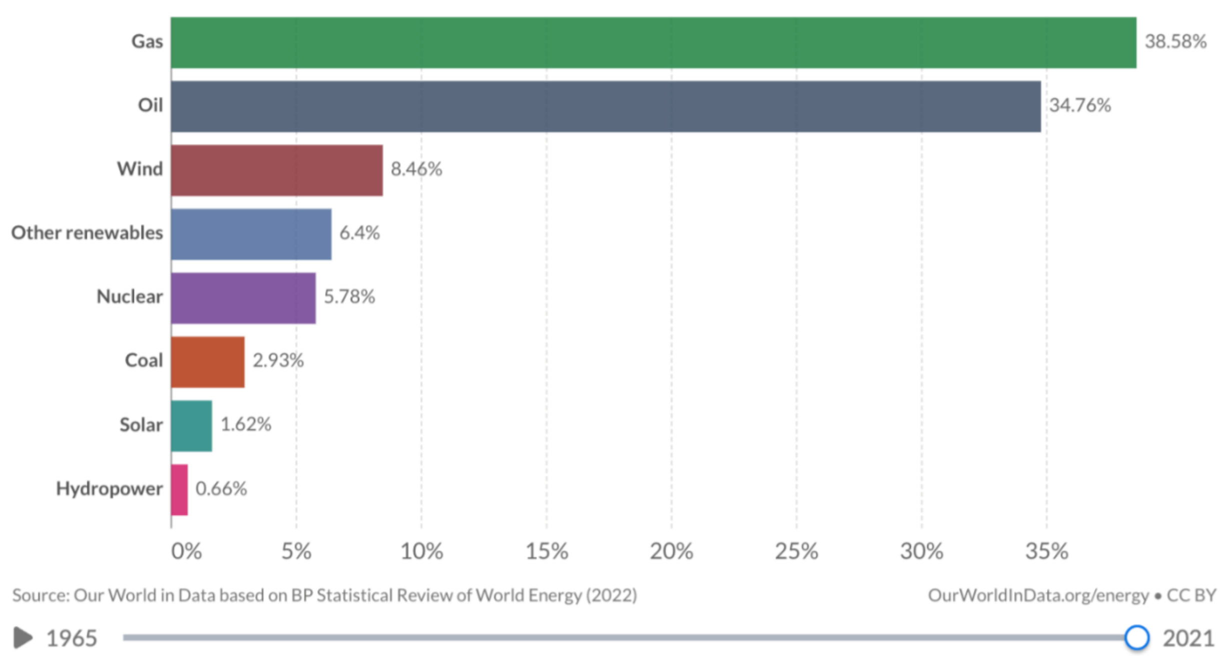

Figure 4.4 Share of energy consumption by source, United Kingdom 2021 (Ritchie & Roser, 2019)

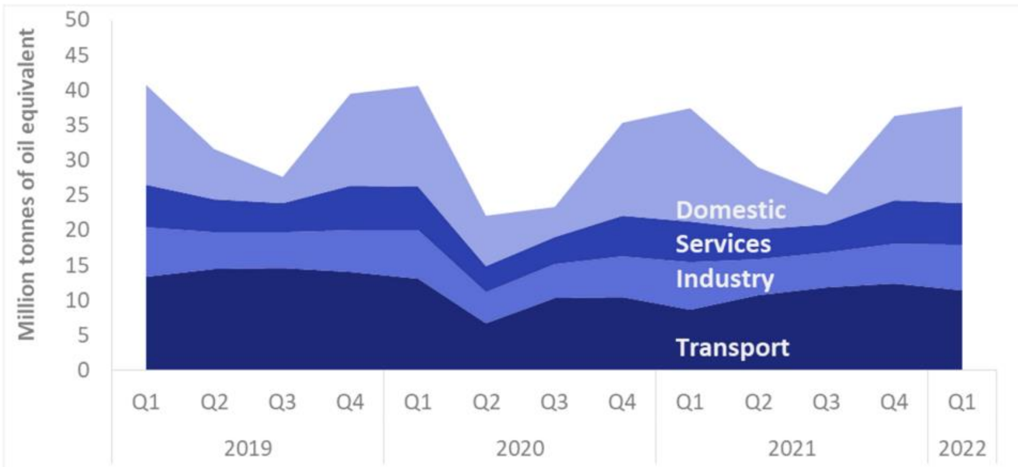

Figure 4.5 Final energy consumption by user (Beis, 2022)

According to the British *Department for Business, Energy and Industrial St*rategy (Department for Business Energy and Industrial Strategy, 2019) from the electricity generated in 2019, natural gas accounted for 40.9%, renewables 36.9%, nuclear 17.4% and coal, oil and others 4.8%. Even though, as we can observe, carbon-based fuels reported most of the electricity production, reports confirm that in the third quarter of 2019 (July, August, and September) renewables generated more electricity than fossil fuels, being the first-ever quarter where renewables outpaced carbon-based fuels. Recent data from 2022 indicate a similar pattern, where in the first quarter of the year electricity generation by renewables was above fossil fuels (Beis, 2022).

4.8 Summary

The research in this thesis is divided in three different stages each using different methods (interviews, FGs and surveys) designed with the specific aims in mind. The use of mixed methods was thought likely to provide a broad perspective to the examination of public perception of ammonia-based systems. It takes into account the fact that green ammonia will be a new concept for most people. Using both qualitative and quantitative data, will allow both the examination of relationships between variables of a wider context and allow freer expression of opinions and any attitudinal complexities or conditional support to emerge. This enables a more robust understanding about public's attitudes towards ammonia and their context.

It is important to take into account that the main researcher carried out data collection throughout the two main phases of the research and that this could have impacted the outcome of the research. A personal statement was included describing the personal motivation for analysing public perception of ammonia technologies and how these could be integrated into technology design and development.

This chapter concludes by exploring the importance of developing cross-national research and presenting the socio-political context of Mexico and UK at the time of the research. It highlights relevant events and context that are important for interpreting the research results. This includes weather patterns and government decisions directly affecting the energy sector of the county.

Chapter 5. PHASE 1- INTERVIEWS

5.1 Introduction

This chapter is divided into two sections: methods and results. The methodology section introduces the tools used to collect and analyse data for the purpose of phase 1 (interviews with experts). A rationale of phase 1 is presented at the beginning of the chapter, along with the description of the study and an explanation about how the data was analysed.

In the second section, the chapter starts by briefly introducing the structure of the results. It is divided into four subsections, where the answers for each set of questions are analysed following the interview protocol structure. After understanding the reasons why experts are working with ammonia-based systems, the research examines perceptions of advantages and disadvantages of the technology, as well as concerns, benefits and risks. This is followed by the perceived role of laypeople, perception of future costs and views about using ammonia to store excess energy from renewables. Lastly, the chapter presents the conclusion and briefly discusses limitations.

5.2 Methodology

5.2.1 Rationale

The first part of the research (phase 1) consisted of 11 interviews with experts in ammonia systems and renewable energy projects. The aims of this section are:

(1) To gain a better understanding of why ammonia energy technologies are being developed and how these are envisaged to be part of a future energy system. Findings from this phase will also be used to create materials for presentation to public participants in phase 2 of the research.

(2) To understand key risk and benefit perceptions of green ammonia among those involved in its development (for comparison with public perceptions).

(3) To understand whether and how experts involved in the development of green ammonia perceive public perceptions to be an important aspect of technology development.

Even though ammonia is a well know chemical around the world, the concept of 'green ammonia' as a fuel or as a storage method is a novel idea. Information about which specific factors influence public and experts' perception on this type of technologies are not yet studied. Therefore, this first phase of the research will provide us with the necessary information to analyse experts' perceptions of green ammonia technologies and compare these with public perceptions in later chapters (*Chapter 8*). It also provides an opportunity to assess to what extent those developing ammonia energy systems consider public perspectives in their research and decision-making.

As it was highlighted in the introduction (*Chapter 1*) and literature review (*Chapter 3*), involving the public at an early stage is important for any energy technological development to facilitate its deployment. Experts and the general public most of the times perceive risks in a different way (Bostrom, 1997); this diverse perspective should be seen as a complementary tool for any development instead of a disadvantage. Studies reveal that perspectives from members of the general public uncover problems, issues and solutions that sometimes are missed by experts. Second, citizens should be able to be part of decisions that affect their community. Third, effective public participation can lead to better results, for instance, technological applications and developments that are socially accepted ((Fiorino, 1990).

Due to the reasons detailed previously, this research is considering both, the experts and laypeople perceptions of green ammonia technologies. We have pointed out the need of a mutual collaboration at every step of the process of emerging technologies between these two actors, leading to a collective responsibility within science and innovation. This study intends to facilitate and create an understanding around the perception of green ammonia in line with the Responsible Innovation Framework (RIF), which opens new opportunities to create value in society through science and technology and to create "*Science for society, with society*" (Owen et al., 2012).

5.2.2 Sampling

The sampling criteria targeted experts that are currently involved in developing ammonia energy technologies for the use with renewable energy. Interviewees were recruited from the database of Dr. Agustín Valera Medina, Associate Professor/Reader at the Engineering School from Cardiff University. The contacts were obtained through different projects Dr. Agustin Valera-Medina has collaborated on in the past. A list of 20 contacts was shared with Andrea M. Guati Rojo, who contacted them via email. From the database 11 contacts responded and interviews were scheduled.

5.2.3 Description of the study

The first phase of research consisted of 11 semi-structured interviews with experts from different backgrounds on green ammonia or renewable energy projects (*see Table 5.1*). These interviews were designed to ask specific questions about different topics on ammonia energy:

<u>Reasons for developing ammonia-based energy technologies</u>

Q.1 Why are you developing the technology specifically with ammonia?

Q.2 What do you think about ammonia as an energy vector, for power distribution and storage?
Q.3 Why these technologies have been developed?
Q.4 What are the main advantages of working with ammonia?
Q.5 What are the main disadvantages of working with ammonia??

Risks and benefits associated with ammonia use

Q.6 What would it be your main concern if this technology is implemented?
Q.7 Which benefits you associate with this technology?
Q.8 What do you think the main risks are or will be once it gets to a commercial stage?

The perceived role of laypeople in developing technologies with ammonia

Q.9 Do you think is important to understand how people perceive ammonia?
Q.10 Do you think public perceptions are important in the development of ammonia-based technologies?
Q.11 At what stage of the technology?
Q.12 How do you think general public will respond to ammonia-based systems?
Q.13 What do you think public will be more interested in, ammonia for energy storage/distribution or for energy production? Why?
Q.14 In your current work with ammonia, are you considering people's perceptions?

Perceptions and expectations about future costs of these technologies

Q.15 How affordable do you think this technology will be once it gets to a commercial point?
Q.16 Do you consider cost to be an advantage or disadvantage for ammonia-based technologies?

Perceptions about renewable energy as energy production technologies

Q.17 What are your perceptions about renewable energies and storing excess energy as ammonia?

[See *Appendix A.1* for complete interview protocol with general prompts]

Questions at the start of the interview were designed to allow participants to express their opinion without any previous association and then become more exploratory towards the end. Qualitative methods were chosen as a first step in the study to obtain a general idea of expert perceptions of renewable energy and ammonia. A secondary aim was to capture and understand more technical aspects of the technology, which could be useful for materials and information presented to the general public in later research phases.

The eleven semi-structured interviews took place between 3rd August and 26th September 2018. Dialogue with participants started via email to obtain informed consent and enable participants to ask any questions they may have and in case they feel they require any further information.

Table 5.1. Demographic information of participants in phase 1.

	PARTICIPANT[10]	AGE	BACKGROUND		COUNTRY
1.	Aaron	38	Academia	Environmental Engineering	United Kingdom
2.	Charlotte	52	Academia	Environmental Engineering	France
3.	Ethan	38	Industry	Fertiliser Industry	Norway
4.	Isaac	42	Industry	Ammonia Energy	United Kingdom
5.	Jacob	51	Industry	Ammonia Energy	The Netherlands
6.	Kevin	76	Government	The Cabinet Office (Ammonia catalyst expert)	Japan
7.	Noah	[11]	Academia	Environmental Engineering	United Kingdom
8.	Nigel	26	Industry	Ammonia as a Maritime Fuel	The Netherlands
9.	Robert	72	Government	Welsh Government Energy advisor	United Kingdom
10.	Ross	29	Industry	Fertiliser Industry	The Netherlands
11.	Tom	40	Independent	Ammonia Energy	United States

5.2.4 Data analysis

The 11 semi-structured interviews were carried out by the main researcher at Cardiff University, UK, via telephone and online platforms (e.g. Skype). Face to face interviews were not possible due to the different location of participants (*see Table 5.1*). All sessions were scheduled for 30 minutes, with the duration of the interview varying between 30-50 minutes.

Interviews were carried out in English, each session was audio-recorded and then transcribed by the researcher after which they were transferred into the software NVivo 11.4.3 for coding. The analysis strategy was based on thematic analysis (Evans & Lewis, 2017). Thematic analysis consists of dividing the text into data units to then identify, analyse and interpret patterns of meaning (themes). These "themes" are identified in terms of whether it captures something important in relation to the overall research aims (Braun & Clarke, 2006).

Thematic analysis was also considered appropriate because it allows pre-defined topics to be analysed (e.g., those from the interview protocol such as *reasons for developing ammonia technologies*) but at the same time it allows for new emerging themes as interviewees may want to discuss aspects not currently part of the interview protocol.

[10] The names of the participants in this study are pseudonyms.
[11] Participant 7 decided to not disclose his age.

During *Chapter 4* (general methodological approach) we discussed that qualitative research is associated with a constructivist epistemology, grounded on the idea that there are ‘multiple truths’, based on one’s construction of reality. In this context, thematic analysis was selected as the analytical tool for the qualitative methods in this study. It enabled us to examine, from a constructionist methodological position, perceptions of green ammonia and associations with additional fuels. Additionally, it allowed us to understand the context of perceptions, how participants construct their perspectives of ammonia and how they envisage the future of this technology.

Before the interviews were fully analysed, general codes were created based on the literature review. New codes were also added as the interviews and analysis were conducted and new themes emerged. Once all data was obtained, transcribed and analysed, the thematic analysis took a cyclical process going back and forth for data familiarisation until the final themes were created. Analysis was based on a hierarchical coding procedure where general categories were coded first following the interview protocol structure (see *Figure 5.1*) and more specific coding was primarily done within these general codes.

The interview protocol was developed as a guide for the interviews but also served as a guide for the analysis. Previously established themes served as a basis for further analysis. For this reason, we can state that under the thematic analysis this research took both an inductive and deductive approach (“bottom up” and “top-down” way). First the analysis consisted of engaging with the literature prior analysis to create predetermined codes (top-down) to later redefine them and create additional themes emerging from the data (bottom up). For the complete coding structure see *Appendix A.2*.

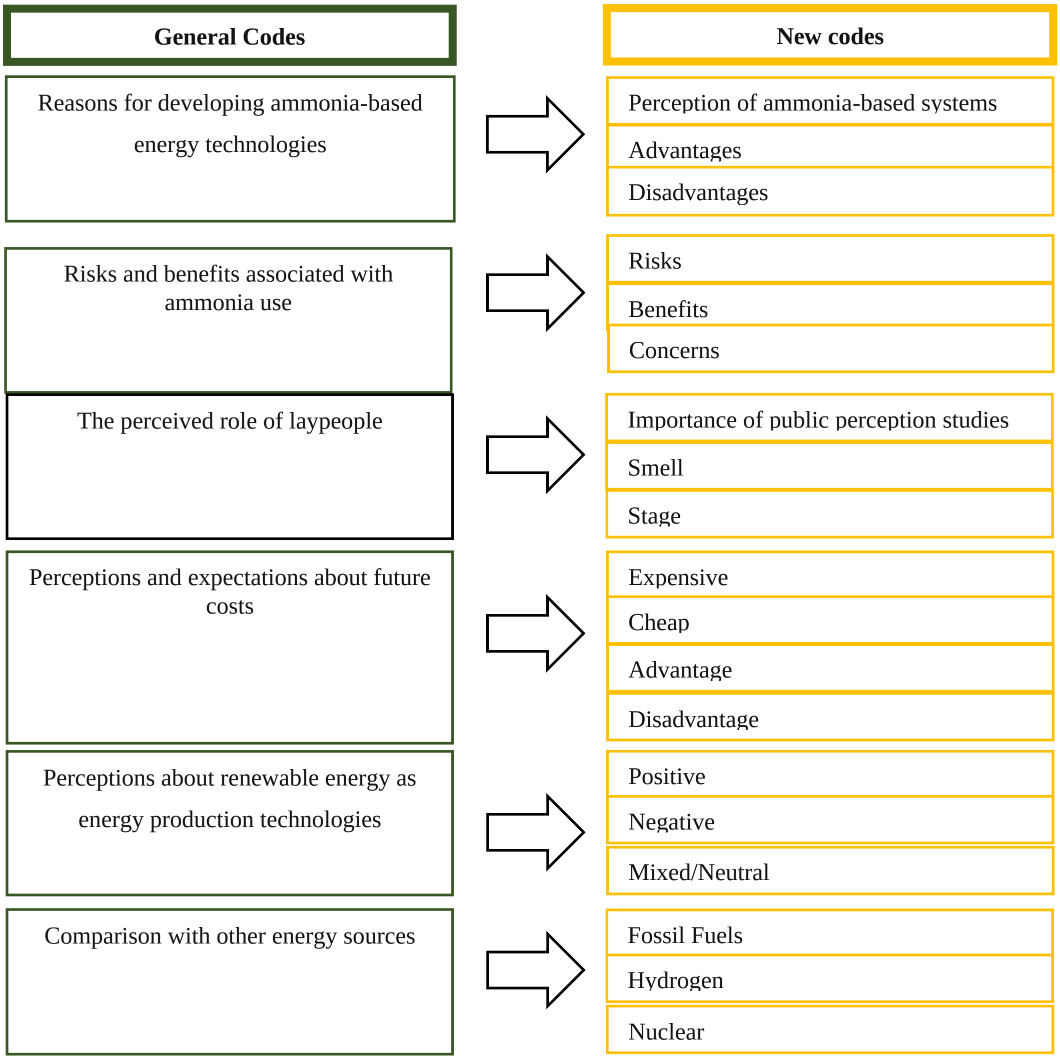

Figure 5.1. Codes for phase 1: interviews with experts

5.3 Results

This section is divided into four sections, where the answers for each set of questions are analysed (see *Appendix A.1*). After understanding the reasons why experts are working with ammonia-based systems, the research examines perceptions of advantages and disadvantages of the technology, as well as concerns, benefits and risks. This is followed by a section on the perceived role of laypeople, perception of costs and opinion about using ammonia to store excess energy from renewables.

5.3.1 Reasons for developing ammonia-based energy technologies

As a first step, the interview protocol was designed to understand the type of technology the experts were developing and to get better insight into the reasons why they decided to work with a component like ammonia, which is new in the energy industry. The answers provided to this first question were similar amongst all the interviewees.

Despite the fact that the professional background from the 11 experts interviewed was diverse, the main purpose of developing a technology specifically with ammonia was essentially the same - that is the need for a carbon-free energy vector. Participants working in the existing ammonia industry framed this as a need to find new ways to decarbonize their current ammonia production and considered it a business opportunity for exploring other uses of the raw material they currently produce for chemicals. Interviewees in academia find working with ammonia an interesting subject in terms of research rather than for economic reasons, as there are many things about this gas that are still unknow and that can be explore as part of the development for ammonia as an energy vector. Both interviewees working for the government highlighted the need of a low carbon energy system and the potential of ammonia to support the deployment of renewables, e.g., by providing a long-term energy storage option.

Industry:

> "Well, so for the company I work for, we are very big producers of ammonia, so it only makes sense that we look at things we are good at which is producing ammonia, so finding other ways to sell more ammonia is only natural to look at." (Ethan, 38)

> "We have been working with ammonia for over 100 years as a company, in the past we used coal as a feedstock for making ammonia, later changed to natural gas because its more efficient and cleaner, now we are on the edge of another change in technology where we need to get completely clean ammonia." (Ross, 29)

Academia:

> "Four years and a half ago, we received some people from (name of an energy company) one day and they proposed to use ammonia as a fuel. Initially we didn't see a lot of future, but it was an interesting subject, it was something that was different, so we said okay let's give it a go and then see how far this can take us. So, It was initially just pure research interest." (Aaron,38)

Government:

> "…clearly we need a low carbon system and we've been moving from high carbon materials such as oil and coal to methane and the natural next step is to move into hydrogen, which is zero carbon, so ammonia it's attractive in that sense." (Robert, 72)

5.3.1.1 Advantages and disadvantages of working with ammonia

When asking experts about the advantages and disadvantages of working with ammonia, a clear difference in responses was found. While positive answers were focused more on the external elements of ammonia such as knowledge and storage, negative comments centred on properties of this gas, such as its toxicity.

Advantages of working with ammonia

As it was mentioned before, ammonia as a *carbon-free vector* is the main reason why people are working with ammonia, however when asking what the main advantages are, zero-carbon was not the first thing the interviewees mentioned. However, it remains to be seen whether this is always the case for experts or it was just due to the order of the questions, where the first answer already implicated talking about zero-carbon properties of ammonia, what it can mean not mention it again as the main advantage.

Considering that ammonia has been on the market for more than 100 years and is the second most used chemical in the world, all participants mentioned the *established knowledge* as one of the most positive things about working with ammonia:

> "What I mean is that there is an established production industry set up for it already, it has a value in the market today and the infrastructure we need already exist to a quite significant extent, which is useful, because we can piggyback on it in terms of moving around ammonia for energy use. We can use the infrastructure and the handling procedures" (Isaac,42)

> "…we have good knowledge on how to handle it. So, I believe is going to be part of the energy mix" (Aaron,28)

Potential for *energy storage* is another positive association every participant mentioned:

> "the advantage of working with ammonia is the versatility and the need for a green fertilizer industry as well as the need for energy storage in the future, renewable energy storage rather than using a battery like a lithium ion battery" (Jacob, 51)

> "[the advantage of ammonia] it's due to the storage conditions and price wise level. Because you want a renewable fuel with the least amount of space, the least amount of mass and the most acceptable pressures and temperatures" (Nigel,26)

"[Ammonia] is incredible easy to store, you can then just put it under a bit of pressure and then liquefy it again and you can move it anywhere you want" (Aaron, 38)

Zero-carbon fuel was the third characteristic most mentioned as an advantage for working with ammonia. However, as it was emphasised in the earlier statement, the reason for being the third characteristic mentioned and not the first, could have been due to the order of the questions and not the order of importance from participants. Answers for this characteristic were brief in comparison with the other positive properties of ammonia "It's carbon free" "No carbon" "Reduces our CO_2" "No carbon atom" "you will get water not CO_2."

Disadvantages of working with ammonia

On the other hand, when discussing disadvantages, the answers were focused on the properties of ammonia as a compound rather than on the system surrounding it. 10 out of 11 experts mentioned toxicity as the main disadvantage about working with ammonia, where four of them considered this as a negative aspect in relation to public perception: "I think the main disadvantage is most of people are concerned about the toxicity of ammonia" (Kevin, 76) "(…) but again people just immediately they start smelling it they start thinking that they are going to die, so it is again that misconception of, again being more toxic than things that are already around us" (Aaron, 38)

In almost every case, participants felt the need to associate toxicity with something else, such as smell, public perception and health and safety. NOx, like in the case of CO_2, was mentioned only in passing and not in detail: "you might also generate NOx" "It produces NOx" "if you burn it you might get NOx" "NOx emissions"

Additionally, it is important to highlight that when experts were asked about the disadvantages of working with ammonia, they mentioned toxicity as a negative aspect but mainly for public perceptions rather than a disadvantage of working with it. They implied that it is something they can tolerate but the public would not, despite the fact that general public coexist with different types of fuels on a daily basis. It is possible that this is due to a perception from experts that toxicity is something that can be controlled and managed, hence expert risk perceptions around toxicity are relatively low ((Siegrist et al., 2007).

"The main disadvantage, for the public, is that it's not as safe as clean water, let's put it that way. So, you need to have some measures in line" (Aaron,38)

“I’m not sure there are many, I guess the use of ammonia because people are not use to it so it can be toxic, but in fact if we use it well there is no problem…” (Charlotte, 52)

“Most of people are concerning about the toxicity of ammonia so I guess in the future we just use ammonia in an industrial area […] if we are aware of the toxicity we can use it in our daily life too, but people might be afraid of that” (Kevin, 76)

5.3.2 Concerns, Benefits and Risks associated with ammonia use

5.3.2.1 Concerns about developing ammonia as an energy vector

It seems that the discussion around concerns was mainly focused on two aspects: costs and the ability to keep up with the demand. When talking about costs, experts mentioned the difficulty of setting up a new technology in the energy industry and the cost compared to fossil fuels, however none of them went into much detail later in the interview when asked directly if they considered cost an advantage or disadvantage.

Regarding high demand, experts were concerned about not being able to produce enough green ammonia to store or transport energy on a large-scale if it becomes commercial. We need to consider that ammonia is the second synthetic chemical most used in the world with a production of over 176 million metric tons a year and a market worth more than $100 billion US dollars (Pattabathula & Richardson, 2016). Currently this ammonia production is entirely based on natural gas, which contains carbon.

Another factor that is worth noting is that in this question, *public perception* was mentioned for the first time with three participants being concern about public rejecting the technology because they do not understand it:

“Public perception, with a few accidents people will lose confidence” (Robert, 72)

“Public perception, the technology has demonstrated that it works, we can deploy it in large scale very quickly, really, it’s people who need to understand that this is possible and that you can do it with an acceptable level of risk, but I don’t think people understand” (Isaac,42)

Answers to this question suggest that some experts think public acceptance will be a barrier for technology implementation. It also suggests that they believe providing more information and educating people may be a solution to this problem. This deficit model of public understanding of science (and this case ammonia technologies) is discussed in more detail later in this chapter.

5.3.2.2 *Benefits*

In contrast with the answers from the advantages section, all experts did mention 'CO_2 free' as the main benefit of using ammonia to store and produce energy. They framed the answer as a solution for a problem, the problem being climate change and the solution a carbon free fuel.

"The benefit is mainly emissions of course, it eliminates all carbon" (Nigel,26)

"So, decarbonization, I can see at things from a very simple sort of product marketing perspective (…) ammonia solves that, so I think that is the reason we're doing this and people talk about economic reasons (…) we are not doing this because is cheaper. We're doing this for decarbonization and that's very clear to me" (Tom, 40)

Another benefit mentioned was *energy independence* - ammonia will allow remote areas to be self-sufficient and to produce, store and consume energy as well as to produce fertilizers at the same time. Three of the experts mentioned this concept and explained how it would bring sustainability and independence to some regions far from the national grid.

"People for example in regions that are far from the grid and the location are open spaces I don't think they will have any issues, I think they will find it very interesting that they can be independent from the fossil fuels process and actually they can become eventually producers of a chemical that is of high profit." (Aaron 38)

5.3.2.3 *Risks associated with ammonia technologies*

When discussing risks of ammonia technologies, participants were asked specifically "What risks do you associate with ammonia technologies if they get to a commercial stage?" This question had the objective to analyse, not just the risks of ammonia as a compound or the production, but to understand what concerns experts might have about ammonia in the future and what challenge it might face once it gets to commercial stage.

Similar answers among participants were found: the established fuel market, politics and safety were the main topics mentioned. Nevertheless, in this answer, market (understood as the fuel industry) was not related to demand, as in previous answers, but to politics and to the competition with the current production of fossil fuels. As discussed in *Chapter 2*, this is often called *lock-in* and it refers to the established system that often lock-in the market to make it more difficult for new technologies to breakthrough.

Participants talked about several interests being involved now in terms of energy and the challenging scenario for a new fuel to enter the current market: "… the moment you take a country that used to be an energy importer and say they won't need to do that anymore, you change politics" (Tom, 40).

"Risk? yes. Again, talking about what is the stage of ammonia compared to other energy vectors it would have a problem in terms of market with fuels like for example oil and gas big companies like BP Shell etcetera" (Aaron, 38)

Answers from these interviews are in line with a previous study from (Brown, 2012) presented in *Chapter 3*. The study involved 26 interviews with members from the Ammonia Energy Association, also from different backgrounds (academia, government, and engineers); according to interviewees the three main possible challenges of ammonia as a fuel technology are 'ammonia status- quo' as an emerging technology (24%), no government support (21%) and the competition with other fuels (14%), such as natural gas. The research also details the lack of support from the government and highlights the need of the latter to make ammonia fuel possible.

5.3.3 The perceived role of laypeople

This section in the interviews intended to understand how experts believe the general public will respond to ammonia-based energy systems in the future and the importance of considering public's views while developing a new technology, especially with a new fuel.

The first question in this section was "Do you think it is important to understand how people perceive ammonia?" The expert answers to this question can be divided into three categories:

- *It is important*: Most of the participants agreed it is fundamental to understand public views of ammonia-based systems, especially because if people do not understand what it is about and how it would work, this might result in fear and rejection of the technology.

- *Just in some circumstances*: Three of the experts mentioned that it is important just if the technology is close to them. For instance, if ammonia is going to be used at a large scale as an energy carrier for large installations between continents, then the public would not be close to it, therefore the experts assumed the general public do not need to know about the technology and experts should not consider them in the development of these technologies. Nonetheless, if you are using ammonia as a fuel for a passenger vehicle, then you will need public to support to develop the technology:

"(…) because if people are against it, it will become difficult to do anything with it, but if people aren't, if they don't know, you can make great progress in industries like international shipping, like heavy duty haulage trucks even things like trains. Passengers don't really care about that stuff, but if you try and put it in a passenger vehicle, that's a whole different question" (Tom, 40)

- *Not at all:* One of the experts mentioned it is not important at all to consider public: "I think general public is unlikely to be that sophisticated. I mean, look at what they have at the moment. […] safety could be a problem but again, look at all the fuels that are out there, people don't care, they don't even understand them and still use them" (Noah)

5.3.3.1 *At what stage should public perception be considered?*

When asking about the stage at which public perception should be considered, seven of the experts agreed it should be at an early stage, in parallel with technology development: "I think that if we don't do it in a primary stage where we know what we are targeting, it would be probably too late by the time that we are at the end of the engineering concept and development to then spot those things and we would have wasted many years in doing so without taking into account public perception" (Aaron, 38)

For the remaining four experts, opinions were divided regarding when to involve public views. One of the experts mentioned at a final stage but before is commercial, another expert at a middle stage and other two of the participants believe public should be involved once it is commercial.

<u>Public responses to ammonia</u>

Similar answers were found when asking specifically how the experts believe people will react to ammonia technologies. For the general public the idea of using ammonia as a fuel would be a new concept and this might represent a challenge for the technology. However, most of the experts emphasised that education would mean acceptance for the technology. According to almost every interviewee, the public will be scared because they would not understand it. *Figure 5.2* reflect the word frequency for this question, as we can observe the words *explain*, *understand, suspicious, hesitant* and *educate* were mentioned several times.

After previous responses regarding disadvantages and concerns were analysed, along with the perception of ammonia response in this specific answer, we can conclude that for experts, the public is seen more as a barrier for the development rather than an enabler.

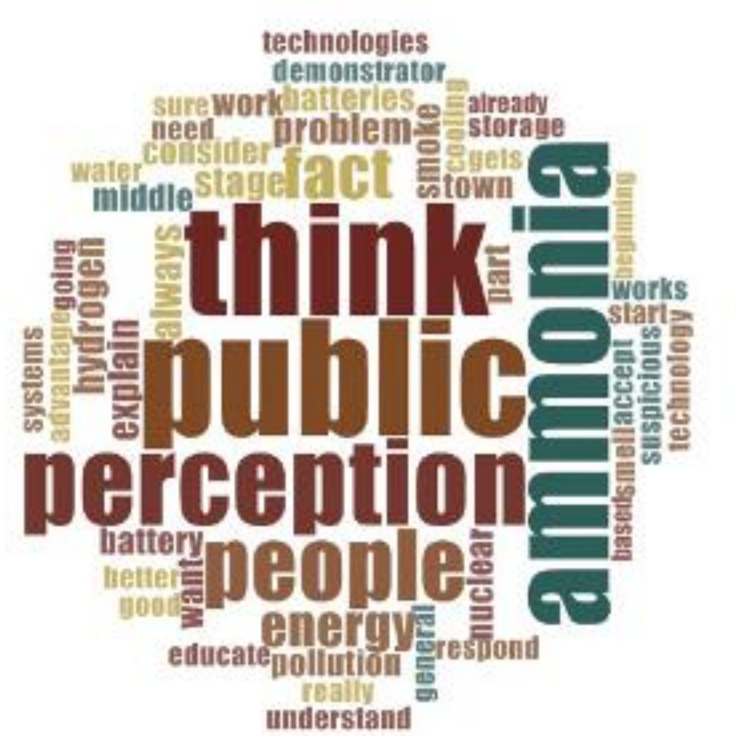

Figure 5.2. 50-word Frequency Ammonia response

Additionally, two of the experts answered "I don't know" but followed by a comment about general public being complicated and difficult to understand and predict.

Answers focusing on the need of education for the acceptance of the technology to this question are a clear example of experts evoking the *deficit model of public understanding of science* (Sturgis & Allum, 2016). As discussed in *Chapter 3*, this model intends to explain attitudes from laypeople towards science, assuring that knowledge is related to public opinion and decision-making is based on accurate information. In this set of interviews regarding ammonia, experts' answers can be related to this approach, where they claim that more information relates to acceptance of ammonia technology and consequently, a possibility to help develop the technology.

<u>General public interest in ammonia: for storage, distribution or fuel?</u>

Answers to this question were broad, most of the experts consider ammonia attractive for the public as an energy storage/distribution medium, functioning as a large battery and transporting energy over large distances. Fuel was mentioned as well but just in the maritime industry.

Renewable energies were mentioned several times here, where experts framed the answer around these technologies. It was thought that using ammonia for storage would have more acceptance from the public because will enable green technologies and then ammonia will be perceived as something positive:

"It also has the attraction that if you are working with intermittence, renewables which are weather dependant, that you can use it as an energy storage medium so you can use hydrogen for power, for heat, for transport, if we can solve all the problems, it looks like a very interesting long way forward, long-term way forward technology" (Robert, 72)

5.3.3.2 Considering Public Perception in their own work

Asking people involved with ammonia if they were considering public perceptions in their current work was the last question in this section. This was asked with the main intention of understanding if the answer from Q.9 "Do you think is important to understand how people perceive ammonia? And Q.11 'at what stage?" was related to the answer for this question.

It was observed that most experts (7 out of 11), are aware of the importance of considering public perspectives for the development of new technologies; their answers reflected that the public should be included in an early stage, while it is being developed or at a commercial stage. Nevertheless, despite the fact that they consider public perceptions as an important pillar in the technology development, just one out of eleven people working with ammonia is in fact considering public or thinking about including them.

These answers raise the question whether they just answered that because they felt it was the 'socially acceptable' thing to do or a misconception of the term *public perception.* It looks like when experts talked about general public perception they were referring to invest time to health and safety aspects and reliability of the technology, but not actually including the perception of people in the development.

> **Researcher**: In your current work with ammonia, are you considering people's perceptions?
>
> **Ross**: Yes
>
> **Researcher**: In what sense?
>
> **Ross**: In terms of security, in terms of affordability, in terms of landscaping packs, so you know there is, we try an issue planning guidance for wind farms because we have decided that the environmental disadvantages of fracking outweigh the benefits.

5.3.3.3 Smell

The main characteristic of ammonia, and one of the most controversial aspects of the technology, is the distinctive odour of the gas. Ammonia's penetrating smell is seen mostly as a disadvantage by the general public (Guati Rojo, 2017). On the other hand, for experts the smell is a great opportunity to detect a gas leak. Nevertheless, regardless of what experts might think about the technology, they are aware of the negative impact that smell might have in the eyes of the general public.

Ammonia occurs naturally in air, soil and water and is also produced by all mammals in their normal metabolism. According to the Agency for Toxic Substances and & Disease Registry (ATSDR) (2004) due to the irritating smell of ammonia, it can be perceived when it is in the air at a level higher than 50 ppm, which means that a person will probably smell ammonia before is exposed to a concentration that may harm them. However exposure to high levels of ammonia can cause irritation and serious burns in the mouth, lungs, and eyes (ATSDR-CDC, 2004).

Expert opinions about the smell as an advantage or disadvantage for the technology were similar. Almost every expert agreed with the idea that ammonia smell is an advantage for the safety aspect of the technology but a disadvantage with regard to public perception. Arguing that due to the levels of concentration mentioned before in the ATSDR study, in a case of a leak, people working with this gas will be able to detect it on time and fix the problem:

"… then again objectively it's very convenient because if you are capable of smelling it in low concentrations which are far from harm the notification of people to get out, in that sense methanol for example, you don't notice it until it hurts you […] so, smell is an advantage in an objective safety way but it does make people more sceptical…" (Nigel,26)

What is interesting to highlight is that despite the fact that they are aware of how relevant is the smell for the technology none of the experts mentioned ammonia odour in the previous questions about advantages, disadvantages, concerns, risks or benefits. Experts only discussed their views on smell once they were prompted by the interviewer.

Another interesting aspect to note is that one of the participants (Noah), claiming that smell was without a doubt a disadvantage, mentioned a new interesting challenge for the technology. As mentioned before, most of the experts assure that ammonia has an advantage over natural gas because of the smell, i.e., it is not needed to inject any substance to make it detectable. However, Noah suggested that this would be in fact a negative aspect in terms of perception and education. People are aware of the smell of gas because we have been using it for a long time and now they know is dangerous. However, with the smell of ammonia, although it might be unpleasant, people do not know they have to evacuate because they are not use to the smell, so in fact we might not need to inject an odour but we would need to educate people in this matter.

Several comparisons were made in this question, three participants linked the smell as a negative aspect because of events that happened in previous years in different countries:

> "… in the past […] in the area of Rotterdam which has small leaks from time to time, made people more sceptical because they didn't like it…" (Nigel, 26)

> "…where Belgium tried to use ammonia for buses and they were filling the bus stations just with ammonia for the trucks because they didn't have enough oil and petrol to make them run but again the problem was that the systems weren't efficient, they were not designed to avoid the smell […] so this place in Belgium was smelling as urine over the entire World War II and obviously people hate it." (Aaron, 38)

> "The smell of ammonia is the same as NG, I don't know how is the perception on NG in the world but in France we don't like it a lot, that is why there is not a real NG in fact in vehicles because people are afraid about gas, so it could be the same with ammonia" (Charlotte,52)

5.3.4 Perception of Costs

Perception of costs associated with green ammonia can be framed as both an advantage and as a disadvantage. In the interviews there were no direct negative comments about the cost of this technology, however all answers included a comparison with the current price of fossil fuels. Costs associated with ammonia can be seen as an advantage when comparing it to other alternative systems and to the future low-carbon energy system because ammonia production and storage may be relatively cheaper. However, when comparing it to carbon-based fuels, ammonia cannot have a significant role in the present, due to the high costs all new technologies represent and because producing ammonia with natural gas is extremely cheap as compared to producing ammonia using renewables (green ammonia).

It is perhaps interesting to note that answers about cost perception were influenced by the time frame in which they were considered. It was noticed that every time experts referred to a negative aspect of the technology in terms of costs (disadvantage and expensive) they used the expression "at the moment" i.e. "A disadvantage at the moment" "it is a bad thing at the moment" "Well clearly a disadvantage at the moment" "For the moment it's expensive" "At the moment, if I am honest with you, it is not profitable". Seven out of eleven experts used this phrase to refer to cost. This suggests that while experts consider cost to be a barrier for green ammonia currently, they may also expect cost to become cheaper in the long term.

As mentioned before, several comparisons were made with fossil fuels and alternative systems. It is important to note that current use of ammonia as a fuel or as an energy storage alternative is not fully developed yet which makes it natural to compare it with existing systems:

> "Imagine that we are competing with fossil fuels and it's very tough to compete with fossil fuels because they are so cheap. But once that changes and we have from our side much more installations in place, costs will go down, and when the price of fossil fuels go up, then I think we will have a proof of concept that is commercially very attractive…" (Jacob, 51)

5.4 Summary

The analysis in this chapter has explored, for the first time, attitudes and perceptions about ammonia-based systems amongst experts in order to gain a better understanding of why ammonia energy technologies are being developed, how these are envisaged to be part of a future energy system, to understand key risk and benefit perceptions of those involved in its development (for comparison with public perceptions), and to understand whether and how experts involved in the development of green ammonia perceive public perceptions to be an important aspect of technology development.

Despite the different backgrounds of interviewed experts (government, academia and industry), all of the participants were clear about the reasons why they are developing new technologies with ammonia, which is to have a low-carbon energy vector. Considering the properties of ammonia, zero-carbon is without a doubt the most attractive characteristic, nevertheless it is important to consider that to really have a "green technology" the whole cycle needs to be carbon-free, this requires obtaining the hydrogen from water and not from natural gas. In this matter, the current price of fossil fuels plays a fundamental role, obtaining the hydrogen from methane is significantly cheaper compared to water electrolysis.

There are additional benefits experts highlighted about this technology such as established knowledge due to the current worldwide production of ammonia. Nevertheless, they also mentioned possible drawbacks of the technology, like toxicity. This disadvantage was framed as a negative aspect for the public rather than a disadvantage of working with it. Experts implied that it is something they can tolerate but public would not, despite the fact that the general public coexist with different types of fuels on a daily basis. It is possible experts perceive the toxicity as less risky compared to lay people because they know how the toxicity risk from ammonia can be controlled and managed.

For future energy systems experts discussed their main concerns relating to costs and the ability to keep up with the demand. Another factor some experts mentioned as a risk is "public perception", it was mentioned that they are concerned about the public rejecting the technology because of a lack of understanding it. In this sense, experts tended to evoke the deficit model of public understanding of science and assumed that education and accurate information provision may overcome this barrier.

Ten out of 11 experts are aware of the importance of considering public perspectives for the development of new technologies, with all their answers reflecting that the public should be included at some point of the development. Nevertheless, despite the fact that they consider public perspectives as an important pillar in the technology development, just one out of eleven interviewees working with ammonia is currently considering public perceptions or thinking about including them.

This chapter provides a comprehensive understanding on how experts perceive green ammonia technology, and the risks and benefits of this technology specifically. Some of the responses from experts are in line with existing research, which suggests that those involved in technological development tend to focus on technical understandings of risk, and that public perceptions are considered mostly important at much later stages of development. The findings also show a homogeneity in perceptions across experts who are currently involved in the development of the technology, something that was not expected but may reflect the fact that the field is still quite small. This might result in general agreement on the benefits and risks of the technology, and the motivation for developing it in the first place (i.e., addressing climate change).

Findings from this phase were used to create information materials to be presented to people in the second stage of the project (*Phase 2.1*: Focus Groups). In addition, expert visions for future ammonia energy technologies will be compared to public perceptions, in line with the RIF in order to highlight any risks or other potentially contentious issues (*Chapter 8*).

5.5 Limitations

It should be noted that the number of experts interviewed for this research was relatively small (N=11), and broader representations should be achieved in future research. Having said that, the sampling criteria was specifically designed to interview those involved in developing green ammonia technology. This expert pool, internationally, is relatively small to begin with. Eleven interviews, when the expertise is specific, is in line with other research which had similarly specific expertise criteria (e.g., Thomas, 2013). In addition, for many of the questions of interest, the experts had similar views which provides some confidence that saturation has been achieved (i.e., not many new views were being discovered in further interviews; Bryman, 2004). It is therefore likely that the current set of interviews has adequately explored expert risk and benefit perceptions of ammonia technologies and found that these are relatively homogenous. Nonetheless, there are limitations to this given the expert pool was so specific and small.

The interviewed experts were all positive advocates of the technology, highlighting its benefits and perhaps diminishing any risks. Future research should widen the type of expertise relating to these technologies to gather a broader set of perceptions, and more critical views. Related expertise might be those with a different technology background but still working with ammonia as a chemical (e.g., fertilisers, maritime fuel, grey or blue ammonia production) to provide more critical views of green ammonia and look more in detail in the variation of the discourse. Experts working in energy storage or low-carbon energy solutions may also be of interest, such as those working with green hydrogen, biofuels, methanol, CCS etc. Thus, there could be a diverse perception of the role of green ammonia in the fuel market, as well as the perceived advantages and disadvantages compared to other alternatives. This would also enable a more diverse background in terms of national context from which the experts are drawn.

Chapter 6. PHASE 2.1- Focus Groups

6.1. Introduction

This chapter is divided in two sections: methods and results. This chapter first describes the methods used to collect and analyse data for the purpose of phase 2, part 1. It begins by presenting a rationale of this phase and justifying the methodology. This is followed by a description of the structure and protocols for the Focus Groups (FGs). It introduces the research strategy and how the sample was selected. Consequently, an overview of each of the FGs is given to provide context for the analysis in following sections.

For the second section, results are displayed in the same order as the interview protocol, divided into six main topics: (1) first associations (2) climate change (3) fuels (4) green ammonia (5) ammonia in Mexico and (6) trust. Each of the topics is analysed and described in detail providing an overview of perceptions in each focus group (FG). To conclude, we include a summary and discussion of the findings and limitations to consider in future research.

6.2. Methodology

6.2.1. Rationale

Phase 2.1 consisted of five FGs carried out in Mexico. The specific aims of this section are (1) to explore people's initial associations and responses to ammonia and its possible use as an energy fuel and storage technology in Mexico; (2) to examine people's risk and benefit perceptions of ammonia as an energy vector in the context of climate change, and to explore other relevant perceptions such as views on governance of ammonia as an emerging technology; (3) to explore public perceptions and understandings of climate change and how different energy sources may contribute to carbon emissions in Mexico.

A qualitative approach was chosen because the aims of this phase are exploratory and it enables capturing people's initial responses and beliefs about ammonia. Furthermore, using a qualitative methodology enables an exploration of how people's socio-cultural context shape opinions and perceptions (Marks & Yardley, 2003).

As chapter 4 discussed, focus groups enable group interaction on a specific topic (Rothwell, 2010). Considering that ammonia for energy power and generation will be a new concept for almost every participant, group interaction was considered to be an important element to allow people to explore the idea together and respond to what other people might think. For this reason, a detail description on how the FGs were constructed and an overview of the participants as individuals but also as a group, is presented below.

When presented with the concept of green ammonia in phase 2 (part 1 and 2), we expect participants to respond in a similar way following the theory of 'preference construction' discussed in *Chapter* 3. When presenting an unknown concept such as a green ammonia, participants in the FGs are likely to understand it through associations based on their prior knowledge, context and personal factors, such as beliefs, values and socio-cultural perspective. Therefore, this first part of the second phase will make sense of how participants perceive green ammonia technology but also what attributes they associate with certain concepts.

This part of the research will provide us with the insights to create the survey in part two (P2.2). Data obtained during the FGs will be then compared to data from the surveys. Afterwards, the analysis from general public will be also compared to perceptions of experts in the discussion (*Chapter 8*).

6.2.2. Research Strategy

The main data collection commenced with five FGs held in two locations in Mexico:

- Mexico City: 4 FGs
- Cancun: 1 FG[12]

The research in both cities provided data that was not confined to one location in Mexico to achieve some level of diversity in responses. Each FG lasted approximately 1 hour, with up to 6-10 participants recruited for each. Participants were recruited to include a diverse range of social backgrounds (e.g., gender, age, income). The FG protocol (see *Appendix B.1*) was generic across all FGs.

The session was broadly split into 8 different sections covering 6 main topics (*Appendix B.1*) and each discussion topic was prompted by questions that encourage participants to discuss their point of view.

6.2.2.1 Participants and recruitment measures

[12] The initial proposal suggested two FGs in Cancun, however due to weather conditions in Cancun one of the groups was cancelled and relocated to Mexico City. (See *Chapter 4* for socio-political context during data collection)

Sampling of participants took both a convenient and purposive approach. Participants were recruited through contacts in the community by the researcher in the specific locations where the FGs took place. The initial stage of recruitment occurred through contacts in the community via email or text messages (convenience sampling). Multiple different locations and communities were targeted to obtain a sample which was diverse in terms of socio-economic background (e.g., employment, income). This was the purposive element of the sampling approach. In each targeted location the researcher obtained one or more contacts which later passed the invitation to other members of the same community until the desired number of participants was reached. Both cities were divided into different zones (see *Appendix B.5*) in order to recruit participants from diverse backgrounds (e.g., gender, age, income), ensuring a broad representation of circumstances and backgrounds. All of the FGs took place in suitable venues (e.g. conference rooms, offices, private spaces) in each location. Detail information about participants is described in section *6.2.5* (Focus Groups Overview)

Participants were informed about the date and time of the FG occurring in their city and the specific zone. Emails contained information about the overall project, further information about the FG stage of the study, and how the data will be used. All communication with participants was in Spanish. Quotations in this thesis are, however, presented in English with translations conducted by the lead researcher who is fluent in both languages.

At the end of every session, participants received an honorarium for taking part in the research at the rate of $350 MXN (£12) for an hour participation.

Focus Group 1 (FG1)
Location: Cancun
Venue: Private house situated in the city centre
Date/time: Saturday 29th June
Duration: 1hr 10 min

Focus Group 2 (FG2)
Location: Mexico City
Venue: Marketing agency office situated in Colonia Roma
Date/time: Thursday 4th July
Duration: 50 min

Focus Group 3 (FG3)
Location: Mexico City
Venue: Private House situated in Ecatepec
Date/time: Thursday 4th July

Duration: 58 min

Focus Group 4 (FG4)
Location: Mexico City
Venue: Offices situated in Palmas
Date/time: Saturday 13th July
Duration: 38 min

Focus Group 5 (FG5)
Location: Mexico City
Venue: Communication agency office situated in Santa Fe
Date/time: Wednesday 17th July
Duration: 51 min

6.2.3. Data Analysis

All FGs were in Spanish to help participants feel comfortable expressing their opinions. Each session was audio-recorded and then transcribed in Spanish by the researcher after which they were transferred into the software NVivo 11.4.3 for coding. Transcription and analysis were carried out in Spanish (first language of the researcher) and quotes included in this thesis were translated to English.

The analysis strategy was based on thematic analysis as there were already pre-defined interests based on the aims of the research (e.g. first associations with the word ammonia) but also this method allowed us to create new, emerging themes as participants discussed their views. Thematic analysis consists of dividing the text into data units to then identify, analyse and interpret patterns of meaning (themes). These "themes" are identified in terms of whether it captures something important in relation to the overall research question (Braun & Clarke, 2006).

This research started with a broader analysis of each of the questions in order to identify key characteristics of the predetermined themes but also to search for new codes. Once an overview was completed, the analysis was based on a hierarchical coding procedure where general categories were coded first following the protocol structure (e.g., Fuels) and more specific coding (e.g., fuels and CC) was primarily done within these general codes. The coding framework can be found in Appendix B, which aided the interpretation and analysis of people's discussion. Within each code, text was analysed to draw out themes that relate to the broader category of interest (e.g., the code 'Green Ammonia – Advantages' covered all text where participants discussed advantages of green ammonia. The text was then analysed for the type of advantages participants discussed). The coding and interpretations of text within each code were discussed with the supervisory team. The interpretations and analysis are documented in section 6.3. Each section provides a series of quotations to evidence a given interpretations and enable other researchers to understand how a particular interpretation was made. Please note, all quotations are fully anonymised using pseudonyms.

Based on previous literature (Braun & Clarke, 2006) it was decided to apply a more reflexive approach within the thematic analysis. Although possible themes were created before the FGs, during the analysis there was a cyclical process going back and forth for data familiarisation until the final themes were created.

As mentioned before, a protocol was developed as a guide for the FGs and later for the analysis. Previously established themes served as a basis for further analysis. For this reason, we can state that under the thematic analysis this research took both an inductive and deductive approach ("bottom up" and "top-down" way). Given this research is a first exploratory study, taking a more pragmatic approach allowed us to combine elements from both types of analysis (Turner, 2014). A "top-down" approach allowed us to explore the literature and create codes that we considered relevant based of similar previous studies. However, because this is the first study on this topic, a "bottom-up" process was needed as well to create new codes or redefine them when the information from the FGs was available.

6.2.4. Focus Groups protocol and structure

At the beginning of the FGs all participants were given a hard copy of the introductory presentation (*see Appendix B.6*) to support the questions and to provide information when needed. The presentation included questions and information about climate change and green ammonia. All the materials presented to participants were created by the researcher and oversee by both supervisors, experts on the topics of public perception (Christina Demski) and ammonia-based technologies (Agustin Valera-Media).

The protocol was divided into 8 different sections covering 6 main topics, in order to elicit different perceptions depending on the topic and the information given to the participants. The main goal was to understand the previous knowledge they had about ammonia and introduce the concept of "green ammonia" and its potential use as a fuel and energy carrier.

It was also considered important to cover perceptions of climate change, given that green ammonia is primarily being developed for use as a low-carbon fuel. Furthermore, it was an opportunity to examine in more depth the topic of public perception in Mexico. Most studies of such nature are conducted in Europe or North America. Findings from this research phase are used to compare public and expert perceptions and to build the questionnaire for the survey in the next phase.

1. First associations

In this section participants were presented with just the word "ammonia" and were asked *"What is the first thing that comes into your mind when you hear the word ammonia?"*. Responses to this question gave us the basis to understand the previous knowledge they had about this gas and their familiarity with it. Even though ammonia is the second most used chemical around the world (Brightling, 2018) it was expected that participants had limited knowledge about it uses and characteristics. Additionally, this question helped us to understand the possible connections participants could create in case of not knowing about the topic. First association questions like this are also useful to gain an initial understanding of people's affective responses to ammonia (e.g., bad, scary), as well as any initial risk and benefit perceptions (e.g., bad for health, good for environment)

2. Climate Change (CC)

After talking about ammonia in a broad sense, the second slide presented was just the word "Climate Change" and a small explanation was given:

"Thank you for all your information. What I want to talk about today is ammonia being used as a carbon-free fuel and its capacity to store energy (like a battery), which I'm going to explain in detail in a couple of minutes. However, the main reason why we are talking about this and presenting this new concept, is because of climate change. Is anyone familiar with the concept "climate change"? Yes, what have you heard?"

The main purpose of this brief paragraph was to explain to participants that there was a connection between the word ammonia and the concept of CC, letting them know that their opinion about this topic was relevant but without giving too much information about the technology.

Acceptance or rejection of the technology might depend greatly on the way participants perceive CC as the most important advantage of the technology is that it does not contain carbon. As a consequence, a slide with basic information and a definition for CC was shown. We were interested in people's perceptions of climate change but also to ensure participants were given basic information on CC prior to the description of green ammonia.

Are you concerned?

They were asked to rate their concern about CC on a scale of 1-10, 1 being not concerned at all and 10 extremely concerned. It is important to note that asking for the level of concern on a scale basis was not part of the initial research plan, however participants on the first FG seem to feel more comfortable when assigning a number to it. In order to analyse data, the following FGs were asked to rate it on the same scale basis.

3. Fuels

This theme was spread out over three different slides in order to analyse participants' views on the current impact of fuels on the environment, as well as their knowledge about zero-carbon energy sources.

As a first approach to this topic, participants were asked within the slide of CC "What do you know about what causes CC?" to see if they would mention energy or fossil fuels.

However, the following slide was more specific about fuels regardless if it was mentioned or not by participants. The slide contained a list of different fuels (hydrogen, diesel, biodiesel, petrol, coal, oil, natural gas and nuclear power) and the first question was "Have you heard about all these fuels?" secondly, "which ones you think are low-carbon fuels?" and finally "Which ones do you think contribute to CC?"

After they shared their views, an explanation about the impact of fossil fuels was presented to them with the same purpose of making sure everyone had the same level of understanding about this topic and present the reasons why we were looking at low-carbon energy alternatives.

"As you can see, fossil fuels play a main role in CC, that is why the need for a carbon-free fuel. Currently, the only two fuels with no carbon in them are hydrogen and ammonia."

4. Green ammonia

After this, ammonia was mentioned again and participants were given a brief explanation of general aspects of ammonia as a component, its current production and uses. At the same time, the concept of `green ammonia' was explained including how the technology could be helpful if used for energy power and storage. Initial concerns and benefits were explored at this point of the presentation.

Afterwards, a table of advantages and disadvantages was presented and again concerns, and beliefs were explored to analyse answers before and after presenting information.

5. Ammonia in Mexico

Ammonia is a compound produced worldwide and as mentioned in *Chapter 3*, mainly utilised in the agriculture sector. Mexico currently depends on ammonia as a fertilizer. According to an article published in 2018 by the consultant company Argus, Mexico imported 33,000t of ammonia between 2012 and 2016 (Argus Media, 2018) through the state-owned enterprise PEMEX.

Taking into consideration all the data about the current ammonia imports in the country, the main objective in this section was to examine participants responses to receiving some further information on the current use of ammonia in industry and what role it plays in Mexico's economy. Four different pieces of information were presented:

- High revenues from agriculture which depends on ammonia as a fertilizer
- Existing infrastructure and knowledge around ammonia is already in place
- In 2016, 63% of the ammonia was imported
- The government has pledged to obtain all the electricity from clean sources by 2020.

6. Trust

The FGs concluded by talking about who participants would trust to regulate green ammonia technology if it was developed in Mexico. The words *government*, *industry* and *both* were included in the slide to elicit public opinions. This topic is extremely important in countries like Mexico where corruption is usually associated with the government and where trust in institutions is a very ambiguous concept. A report published in 2018 (Corporación Latinobarómetro, 2018) indicates that just 12% of the population in Mexico belief in democracy and 88% of people interviewed consider that the government seeks their own benefit instead of the country's.

6.2.5.Focus Groups Overview

Below an overview of each FG is given to provide context for the analysis in following sections. Additional context and reflections are also included.

FG 1– Mid Income, mix of ages

Table 6.1. Overview of participants on FG1
Location: Cancun

PARTICIPANT	AGE	GENDER	OCUPATION	Education Level[13]
1	66	F	Unemployed	High School
2	29	M	Receptionist	High School
3	26	M	Actor	High School
4	50	F	Teacher	University
5	30	F	Accountant	University
6	23	M	Tax consultant	University

[13] See *Appendix B.4* for description of education levels in Mexico

7	22	F	Teacher	University
8	74	F	Unemployed	High School

As described in Table 6.1, FG1 included 8 participants: 5 female, 3 males. 3 males and 2 females were 22-30 and 3 females were between 50-74; half of the participants have a high school degree and the other half a higher degree with university; two of the participants were unemployed.

At the beginning, because of the age difference, there was a clear division regarding beliefs about causes of climate change between young participants (20-30 years), with an anthropogenic point of view, and older (50-74 yeas) participants, stating that CC is causes by natural factors or mentioning consequences but not causes. However, throughout the FG it started to be more homogenous and despite the age difference they had similar points of views on green ammonia.

Participants from this FG had good interaction with very engaging discussions, when the topic about CC was mentioned the experiences from young and older people helped to have a comprehensive perspective about the topic.

Nevertheless, at the end of the FG, when the topic of trust was discussed, opposing political beliefs (left vs right) in the group became evident. This led to brief disagreements between some of the participants, but people were keen to contest opinions in a respectful manner. When it became clear that the conversation continued to be mostly about politics, it was decided to conclude the FG.

FG 2 – Mid Income, mostly late 20s and 30s

Table 6.2. Overview of participants on FG2
Location: Mexico City

PARTICIPANT	AGE	GENDER	OCUPATION	Education Level[14]
1	30	M	Advertising Editor	High School
2	24	F	Student	High School
3	28	M	Graphic Designer	University
4	29	M	Web Programmer	BTEC
5	36	M	Art Director	University
6	61	M	Publicist	University
7	33	F	Publicist	High School

[14] See *Appendix B.4* for description of education levels in Mexico

8	33	M	Web Programmer	University
9	24	M	Publicist	University

As described in Table 6.2, FG2 included 9 participants: 2 females, 7 males. 8 participants were similar in age 24-33 and 1 male was 61; every participant was working in a marketing agency. The majority had a bachelor’s degree and all had a similar socio-economic background.

The FG was held on the premises of a marketing agency and participants were working there as well. Everyone knew each other which made the interaction between participants easier and everyone was comfortable enough to give their opinion.

There was a relatively high level of importance placed on overpopulation as a cause of CC; participants in this FG were all in favour of reducing the amount of children per family in order to stop CC, an idea that other groups mentioned but not in detail. Nevertheless, it is important to highlight that the FG was constituted mainly by men, though the first comment about having less children was discussed firstly by the two female participants. This point is explored further in part 2 of this research (surveys) where participants were presented with a text about overpopulation and its impact and asked if they agree with the statement or not (see *Chapter 7*).

FG 3 – Low Income, mix of ages

Table 6.3. Overview of participants on FG3
Location: Mexico City

PARTICIPANT	AGE	GENDER	OCUPATION	Education Level[15]
1	29	F	Unemployed	University
2	27	M	Unemployed	High School
3	58	F	Owner of a food business	University
4	54	M	Household employee	Primary School
5	42	F	Household employee	GCSE
6	32	M	Accountant	University
7	34	F	Unemployed	University
8	23	M	Driver	University
9	23	F	Student	High School
10	52	F	Household employee	GCSE

[15] See *Appendix B.4* for description of education levels in Mexico

As described in Table 6.3, FG 3 consisted of 10 participants: 6 females, 4 males; 6 participants were similar in age 23-34 and 4 between 42-58; they had a diverse range of education level. Some participants had completed bachelor's degrees, but other participants only completed primary school. Nevertheless, they all had a similar socio-economical background and identified with each other as they lived in the same neighbourhood.

This FG was planned as a substitution for the one cancelled in Cancun (see *Chapter 1*), in order to obtain data from a different sociodemographic perspective. The venue was in Ecatepec, a district on the outskirts of Mexico City. This part of the city is known to be not a very accessible neighbourhood after being declared the most dangerous district of Mexico City in 2019. For this reason, most people started avoiding this region.

Participants in this group are aware of the difficulty to access the neighbourhood and felt grateful to be considered for a study that will have an international impact. Inside the venue the atmosphere was relaxed with great interaction between participants.

This FG was the most familiar with ammonia, as it is a chemical used mainly in the cleaning business in which many of the participants worked. As a result, participants engaged more with the uses of ammonia and the advantages/disadvantages of the gas. Additionally, one of them was well informed about CC.

This group consistently compared the situation in Mexico with that in Europe, especially regarding energy, trust and government. However only one out of the ten participants has travelled to Europe. Also, it was notable that this group was more trusting and supportive of the government to develop this technology in the future.

FG 4 – High Income, younger

Table 6.4. Overview of participants on FG4
Location: Mexico City

PARTICIPANT	AGE	GENDER	OCUPATION	Education Level [16]
1	29	F	PR agency	University
2	28	M	Graphic Designer	University
3	29	F	PR agency	University
4	29	F	Publicist	Masters

[16] See *Appendix B.4* for description of education levels in Mexico

5	28	F	Publicist	University
6	27	M	PR agency	University

As described in Table 6.4, FG4 included 6 participants: 4 females, 2 males; all participants between 27-29 years old; similar range of education level and similar socio-economical background.

The group was noted as being quite homogenous in terms of being extremely worried about CC and their perspectives about most of the topics. The group was smaller compared to other FGs which allowed more time for each individual to discuss their own perspectives rather than engaging with each other as much.

Regarding content and themes, this group was more concerned when talking about CC describing in detail everything they know and what they are doing about this situation, as well every participant was an active member of social media so they were discussing the videos they have watched about "the time left for the planet" - they did not remember the specific name of the video but most participants remembered watching it on Facebook. Additionally, when rating how worried they were about this topic, all gave a 10 out of a 1-10 scale.

FG 5 - Mid Income, middle aged

Table 6.5. Overview of participants on FG5
Location: Mexico City

PARTICIPANT	AGE	GENDER	OCUPATION	Education Level [17]
1	29	M	Driver	High School
2	47	M	Production manager	University
3	18	F	Student	High School
4	51	M	Driver	Secondary School
5	55	F	Domestic Employee	Secondary School
6	50	M	Accountant	University
7	42	M	Manager	High School
8	58	M	Tax Consultant	Masters

As described in Table 6.5, FG5 consisted of 8 participants: 2 females, 6 males; 6 participants between ages 42-58, 1 male aged 29 and 1 young female aged 18; diverse socio-economical background.

[17] See *Appendix B.4* for description of education levels in Mexico

The group was noted as being quite homogenous in terms of concerns about CC. In comparison with other FGs, it felt as if participants took this FG as an opportunity to learn. They asked about the fuels on the list given, before expressing their opinion about the impact of energy sources on CC. Additionally, they were very interested on the topic and kept asking for more information about ammonia and other technologies even after the session was over.

On the other hand, despite the fact that they were not the group with the lowest income, their answers about costs was the lowest of all the others groups in Mexico City; when asked "how much extra would you be willing to pay for electricity if it comes from clean sources?", their answers were between 10%-15%, in comparison with the low-income FG that responded 30%-40%. This will be explored in more detail in the following results section.

6.3. Results

6.3.1. First Associations

What is the first thing that comes into your mind when you hear the word ammonia? What do you know about it? According to your experience, what can it be used for?

Given that ammonia as an energy vector and storage is an emerging technology, it is important to understand first associations with the term *ammonia*. As hypothesized, knowledge around this chemical was limited and the initial affective responses were negative, however some of the participants are aware of some products containing ammonia.

Words like death, toxic, poison, corrosive, pollution and unhealthy were the most mentioned and give indication of some initial risk perceptions people had about ammonia. Urine was just mentioned once by a participant in FG4. Also, *radioactive* was described as a characteristic of the gas in two of the five focus groups (FG1 and FG4); this is important to highlight because some of the associations later in the FGs will be with *nuclear power* and *trust*, due to the uncertainty and fear of a catastrophic event happening.

Additionally, one of the participants associated this word with kidnapping, a topic that also emerged in informal chats about the research with the participants. Occasionally, when explaining to people the research, some of them referred to ammonia as being used when you murder someone or to clean up blood. Ammonia being related to crime scenes might be due to popular culture at the time of the interviews. For example, the television series Breaking Bad presents ammonia as a chemical useful to create drugs and to clean up blood. On the other hand, due to the restricted knowledge around the chemical, the general public might get confused and associate ammonia with other chemicals like chloroform.

When presenting the first slide and asking about ammonia, most answers were short and with not much detail. However, compared to all the FGs we can emphasize that most of the participants from FG3 were familiar with the concept of ammonia. Answers were still short but they were able to associate ammonia with cleaning or other products, nonetheless negative affective responses are still evident (e.g., it's dangerous). This can be attributed to the fact that their professional background, as shown in *Table 6.3*), was dominated by participants working in the cleaning business. This explains why their knowledge about this gas was broader than in other FGs. [18]

"It is toxic, but the product I use to perm my hair contains ammonia" (Lourdes, 52)

"It's a very penetrating substance, is great for cleaning, especially to clean car grease" (Gabriela, 54)

"It is very dangerous but you can use it for compost, fabrics, plastics…. also to kill cockroaches" (Dom, 32)

Additionally, the last FG in Mexico City (FG5) had some knowledge around the concept, which also had a participant from this particular professional background and similar answers to FG3 were obtained in this first section.

"It comes a lot in products for toilets and drainage" (Lino, 50)

"I know the product I use to dye my hair has ammonia" (Marisol, 55)

6.3.2. Climate Change

Is anyone familiar with the concept "CC"? Yes, what have you heard?

When mentioning CC, participants expressed strong emotions about the topic. Despite the fact that there was a considerable age gap between some of the participants (see *Appendix B.3*), everyone was familiar with the concept and had negative feelings about this, referring to it mostly as a "*reality":*

"What do we know about CC? Well, easy, that we are fucked. (Natalia,30) [FG1]
"A reality that reached us and is catastrophic" (Robin, 61) [FG2]
"A reality" (Andrea, 24) [FG2]
"it is a reality we are living in and we can't avoid" (Armando, 28) [FG4]
"What have I heard? That it's scary" (Regina,29) [FG4]
"Reality, something irreversible" (Emmanuel, 58) [FG5]

Table 6.6. Level of concern of participants on 1-10 scale.
1 being not concerned at all and 10 extremely concerned

[18] The names of the participants in this study are pseudonyms.

	Cancun	Mexico City			
	FG1	**FG2**	**FG3**	**FG4**	**FG5**
Participant 1	7	8	7	10	8
Participant 2	8	7	5	10	5
Participant 3	9	8	8	10	5
Participant 4	9	7	7	10	8
Participant 5	7	10	8	10	9
Participant 6	5	10	8	10	9
Participant 7	8	9	9	-	9
Participant 8	7	8	7	-	8
Participant 9	-	7	6	-	8
Participant 10	-	-	10	-	5

The fear expressed throughout the FGs was mainly due to a time frame they have heard over the news and online platforms such as Facebook and Instagram. Some of the participants said they have heard that the population has around 30 to 50 years left to address it.

FG4
Researcher: Is anyone familiar with the concept "climate change"? Yes, what have you heard about it?
Participant 1: 30 years, that is what we have left to save the planet.
Participant 2: 30 or 50 years.
Researcher: Where have you seen that information?
Participant 2: There is a video on social media from the UN.
Participant 3: I think that what the video is trying to say is that if we do not do something right now, in 30 years the world will not be the same. It is irreversible, so we are still relatively in time to take action, do something and have more years with the planet as we know it.
Participant 4: Yes, I've seen that video too.

This idea was causing them fear and a feeling of hopelessness. However, as part of an informal chat after each FG, it was noticed that most participants, despite the fact that they reported being "extremely worried" about CC, did not engage in pro-environmental behaviours. Just one participant out of the 41 said she tried to reduce her meat consumption but mainly for the animals welfare not for the impact on the environment. Similarly, none of the participants had thought about reducing their car use or searched for new low carbon alternatives when travelling. This was often attributed to the lack of public transport in the country. However, participants did state that they were trying to decrease their footprint by reducing the amount of plastic consumption.

This point is interesting because plastic consumption is not directly linked to CC. It's an important environmental issue, but it does not directly cause CC. This suggests that there are still a lot of misunderstandings and misconceptions about the causes of CC in Mexico. Nevertheless, this emphasis in reducing single use plastics as a measure to tackle CC is not only exclusive to Mexico. According to an article from the World Economic Forum, governments and media have been playing an important role in this perception worldwide, "plastic pollution – or more accurately the response of governments and industry to addressing plastic pollution distracts from addressing the real environmental threats such as climate change. […] environmental news has been dominated by the issues of plastic pollution. So, it's not surprising that so many people think ocean plastics are the most serious environmental threat to the planet." (Stafford & Jones, 2019).

Are you concerned about CC? What do you think causes it?

When asking to rate how concerned they were about CC on a scale from 1 to 10, the findings show strong concern. Every participant rated their concern 5 or above, with an average concern of 7.88, independent of gender, age or educational level.

After discussing their familiarity with the concept of CC, their first thoughts and how concerned they were about this topic, participants were asked about the causes in order to analyse the specific knowledge they had about CC. It becomes clear that although participants were worried about CC, the causes and consequences were not well-understood. There seems to still be a lot of misunderstanding and lack of knowledge about the topic.

"What causes CC?" - The most common answer to this question was rubbish, specifically plastics. It is also interesting to note that the word "us" was used in several occasions; most of the times referring to "us" as Mexicans and just a couple of times as humans. We can assume this because at using phrases like "we have no conscience" and asking to explain this idea and why they were feeling that way, they explained the lack of consciousness in Mexico, not worldwide, about recycling and the need of "Mexicans" to keep consuming in an excessive way: "we need to have new habits as Mexicans when we consume" (Beatriz,66) "We have this extreme weather because we have allowed people to keep building in Cancun" (Anonymous, 74) "It is just that in Mexico we are not aware of things, that's why we are the way we are" (René,30).

Other causes mentioned include overpopulation. For example, participants commented saying "we are too many", and "...this is happening because of the way we produce things, an overproduction, but at the end the real reason is that we are too many and we consume more" (René 30).

Currently, Mexico is one of the countries with one of the largest populations in the world with approximately 126.19 million inhabitants (The World Bank, 2019a). Although every FG mentioned overpopulation, the ones from Mexico City engaged more with the topic. Several participants on these FGs even suggested to stop having children as a solution for CC.

Roberto (61): About how concerned I am, well maybe because of my age I'm not worried about myself, but I am for future generations, we don't have enough time and what would happen with people in 50 years? We need to stop this!
Andrea (24): Exactly, when you realize this, your life plan changes completely, you actually need to stop and think if it is worth having kids, might sound hard but we shouldn't keep having children.

"I think we are forgetting the origin of all these problems, overpopulation, if there weren't so many people we would not need to generate so many products" (Luis, 36)

"[…] not sure if there is something today but there was this campaign when I was a kid that said that smaller families live better, today we don't have anything saying to the people, please stop having kids!" (Luis, 36)

FGs with participants over 50 years old (FG2, FG3, FG5) cited a campaign's slogan from the 70's: "*small families live better*". This campaign was launched in Mexico City around 1974, when each family had on average 7 children. This initiative was followed by other communication campaigns and the government was able to reduce the birth rate to 2 children per family (Consejo Nacional de Población CONAPO, 2014). However, this campaign had a lot of criticism from the Catholic Church claiming that the movement was against family values.

6.3.2.1. Climate change and fuels

The previous question about causes of CC also reveals that energy fuels are not on the top of participants' minds as a cause of CC. Participants are aware that fuels have a certain amount of impact on the environment, but it was not the first cause mentioned. Only two participants throughout the five FGs talked about fuels spontaneously:

"I don't think the cause is plastic […] I think there is a bigger impact from cars, petrol and all that" (Natalia, 30)

"I think is the way of producing and the fuels that give energy to those systems […] burning hydrocarbons" "[…] for example I think a transatlantic flight is worse than plastic" (René, 30)

6.3.2.2. Comparisons with other countries

One of the most interesting results in this analysis is the consistent comparison with Europe throughout the discussions. When asking specifically about CC, comments like “In Europe these things don’t happen” “In Europe cars don’t pollute” were stated. We observed that participants associate Europe as an example of how society should behave in respect to the environment and expressed feeling ashamed of Mexico for not doing anything about this problem. When talking about solutions to climate change, European countries were also mentioned repeatedly as leading the way, whereas participants felt they saw no efforts being made in Mexico.

Another relevant finding is that in Mexico, CC might be seen as a problem because of a possible misunderstanding of the concept and a confusion with pollution:

“The thing here is that we have an overpopulation […] but that overpopulation in a small space will result in more waste, more plastics, more smog and pollution, so then you get more CC in some regions like Mexico.” (Dom,32)

6.3.3. Fuels

Here is a list of fuels, which ones you think are low carbon? (Which ones do you think they are contributing to CC? Is there any you haven’t heard of?

Answers provided to these questions were analysed for energy source awareness, with a particular interest in what impact they have on the environment.

When presenting the list of fuels to participants, everyone affirmed to be familiar with them. However, when asked which fuels they belief contribute to CC, most of participants were not able to do so.

Nevertheless, coal was the most mentioned followed by nuclear power, gasoline, diesel and just a few mentions of natural gas. Carbon and nuclear were mentioned throughout the five FGs, with participants affirming that these contribute to CC.

As soon as one participant would mention nuclear power, the rest confirmed that they agreed with this participant; making comments about how dangerous it is for the planet or comments mentioning Chernobyl.

Focus Group 2

Which ones do you think they are contributing to CC?

Roberto: Nuclear energy, no? it has a lot of advantages, but if something happens - oh no!

Focus Group 3

Which ones do you think they are contributing to CC?

Participant 1: Nuclear energy

Camila: Yes, nuclear energy

Gabriela: Exactly

Lourdes: Diesel

Dom: I think all of them, but I consider that the worst is nuclear energy, it is the most aggressive on for the environment.

Focus Group 4

Which ones do you think they are contributing to CC?

Julian: Petrol

Regina: Coal

Daniela: Diesel

Armando: All of them

Daniela: I am not sure what is biomass

Regina: Nuclear energy, even though I am not sure what it is

Daniela: Yes, nuclear energy. If it's not handled correctly it can be a huge problem

Maria: All of them, right?

This result is similar to findings in other parts of the world. For example, Poortinga, Pidgeon and Lorenzoni (Poortinga, Pidgeon, Lorenzoni, Pidgeon Nick, & Lorenzoni, 2005) note that 39% of participants believed that generating electricity from nuclear power causes CC (p.7).

6.3.4. Green Ammonia

[participants were given a brief explanation of general aspects of ammonia as a component, its current production and uses, see *Appendix B.6*]

What do you think about this concept of "green-ammonia"? Do you see any disadvantages or risks in using this technology? Advantages/benefits?

After presenting the concept of green ammonia, participants were still in doubt about their understanding of the technology so different questions were asked by participants in this section of the FG. These questions were indicative of the types of concerns and risk perceptions people have about the technology. The topic most asked about was how much water is needed to develop this technology. It is important to note that Mexico City is living in a water crisis. Experts predict that Mexico City's water reserves will dry out in the next 30 years due to inefficient and ageing water networks infrastructure: about 40% of the water is lost because of this lack of maintenance (Hogenboom, 2018).

Therefore, it is not unsurprising that concerns about water usage are at the top of mind for the participants in Mexico.

Other comments were centred on the difficulty to develop this technology in Mexico due to external factors like the high revenues from the oil/gas industry in the country and the high levels of poverty – it is estimated that 34.5% of the population live in poverty currently (World Bank, 2019). However, despite the difficulties people might perceive for the technology, there were no negative comments about the technology itself; comments focused on external factors instead.:

"For example, for the marketing perspective, I don't think is a good idea because the first thing that comes to mind are negative things […] we need to see the cost-benefit and compare it with other alternatives. I think wind power is easier" (Ramiro,29)

"It sounds really interesting and I believe it could help a lot, however we need to think what are we fighting against, all the political interests and from oil companies" (Gerardo, 51)

"The problem here is that we need to always fight against private interests but there are other more important things, I mean deeper and more severe things like for example poverty, which brings a cycle of more poverty, lack of education and ignorance. If you don't fix that, you cannot thoroughly fix the way of consuming any type of energy" (Jaime, 42)

It was noted that for some participants there were topics, like poverty, which require addressing first before focusing on addressing CC and energy issues. We do know, however, that these aspects are not unrelated. CC is impacting poor communities the hardest as it is extremely difficult for vulnerable areas to recover quickly from shocks such as flooding, drought and extreme temperature variations caused from CC (Ashok, 2020): "CC is going to amplify the already existing divide between those who have resources and those who do not," Eliot Levine, director of the environment technical support Unit at Mercy Corps (McCarthy, 2019)

There were also a number of positive comments about the need for new alternatives to tackle CC.

*"*If there is information, this could be possible, especially because we, as new generations, are open to new challenges and to say "yes, let's try it" but tell the truth about the product, good and bad" (Irma,22)

*"*I think it is great that you can use it as a battery*" (*Ricardo, 23*)*

“We should be open to new things because there are great technologies that could help the environment and we are not using them” (Giselle,50)

Would you be worried about this? Why? What is your main concern about this technology?

Similar to answers about CC, participants thought this was something that could be successful in Europe but not in Mexico: “this could work in Europe but not in Mexico” (Dom, 32). One of the reasons for this answer was that it would not work in Mexico because of poverty and low education levels in the country.

Another recurrent topic was suggestions of alternative technologies they’ve heard about and that might help: “I’ve heard/watched that you can also generate electricity with….” (referring to biomass and biogas most of the times) however, they didn’t know the specific name of the technologies or a lot of detail about them just what they have heard or read on social media.

“I’ve heard that in Cancun they were talking about using seaweed as a fuel’ we have a lot! We should use it” (Anonimous,74)

“I watched on TV that in Europe they use animal manure to produce electricity, they add corn and other things to produce it and then they save this in batteries” (Giselle,50)

6.3.4.1. Perceived risks and benefits

Are there any risks you are worried about the most? What do you think is the most attractive advantage?

After presenting the table outlining potential risks and benefits associated with ammonia, participants discussed these as a group. Two topics were the most relevant for participants in regards to the perceived risks: NOx particles and water.

When participants mentioned NOx particles they were mainly concerned about the lack of regulation in Mexico to monitor these systems. In the table displayed during the presentation, NOx particles were described as follows “if it is not burned properly, NOx particles can be released, contributing to CC.” In this case, large amount of NOx emissions is the result of a faulty system and participants affirmed Mexico cannot be trusted to keep track of this because of perceived and widespread corruption. In this sense, we could argue that the real topic is then about trust, not directly about NOx.

“But then a “bad” procedure let’s say will generate more NOx, then in Mexico we couldn’t do it. We can’t trust” (Natalia,30)

“There is no regulation in Mexico, the NOx thing couldn’t work here” (Beatriz, 66)

“You are saying in disadvantages that if it is not burned correctly then it could generate NOx, then maybe instead of helping the environment it might be the opposite and make it worse especially if it is not used correctly. That is what happens here, that norms, guidelines and standards are not followed […]” (Antonio, 47)

However, NOx particles were not only associated with trust. Some comparisons with nuclear power were found again in some of the comments:

“I guess, for me is the security of the technology, the NOx particles, it might be like nuclear power, that it has a lot of advantages but if something bad happens then PUM! we could all disappear” (Roberto,61)

This suggests that the comparison with nuclear was made due to the uncertainty and fear of a catastrophic event happening with ammonia, which may be exaggerated by the low trust to regulate the technology.

Water was another topic that was mentioned again, however, similar to previous occasions during the FGs, it was discussed as questions not as a complaint about the technology. Participants wanted to know how much water is needed for the technology, where this water would come from and whether all types of water (salt, fresh and storm water) could be used.

It is relevant to highlight that even though smell is one of the main disadvantages highlighted by the experts in the previous interviews, the FGs revealed the opposite. Smell was not mentioned at any point and when the question was prompted the answers were just “No, I don’t mind” “It will only smell if there is a leak, so it’s okay” and not further discussion followed the comments.

In terms of advantages, participants perceive ammonia technology to be an opportunity to help the environment but also to develop a fuel that is safe, simple and convenient. Currently, 97% of the electricity generated in Mexico is through fossil fuels and the domestic gas comes 79% from Liquified Petroleum Gas (LPG) which means that 79% of families still rely on stationary tanks (INEGI, 2018) that need to be refilled approximately every two weeks depending on the tank .

Another perceived advantage was the opportunity to have more alternatives: “Also, for how long we can keep relying on fossil fuels? We need to find alternatives, right? Because fossil fuel will end soon” (Deborah, 34) “But fossil fuels are almost over, we need to look for more alternatives” (Camila,58) “[…] well, there is no other way, right? We don’t have a lot of fossil fuels left” (Dom,32)

A similar response was found in a study about public values for energy system change in the UK (C. Demski, Butler, Parkhill, Spence, & Pidgeon, 2015) where 79% of participants believe the UK should reduce the use of fossil fuels. When asked why, 48% of participants mentioned the unsustainable nature of fossil fuels (‘finite/running out’).

6.3.5. Ammonia in Mexico

What do you think about this information? Is it attractive for you to know that ammonia is being used all around Mexico and this might help to boost a green ammonia technology?

Participants found the information interesting, comments like “wow” “sounds interesting” “I didn’t know that” were frequently mentioned in the FGs.

When presented with Mexico’s target to generate 35% of electricity from clean sources by 2020, participants were nonetheless sceptical, especially because the current president (AMLO) is planning to open a new oil refinery and proposing a new coal plant (see *Chapter 4*). Therefore, participants thought the information was interesting but not something that could help develop ammonia technology. In all FGs the first reaction was to laugh and talk about how impossible it is for Mexico to continue developing renewable energy projects.

“While this man (referring to AMLO[19]) is still in power, we can’t do anything like this” (Anonymous, 74)

“That target is impossible, for 2024 we will be surely using even more coal” (Roberto,61)

“Be careful because they might even kill you if you keep those projects that are against the government” (René,30)

“6 months ago, before AMLO, it was possible, now you can’t even be talking seriously” (Daniela,28)

“Is simple, everything about ammonia to generate electricity is a problem because all this government is focused on is to go back to burning coal and then ammonia starts representing a problem for them […] this new government is not suggesting a future perspective for renewables and it’s doing that because of all the economic interest behind” (Mauricio,58)

People are angry and again they describe these actions from the government to not support renewables as absurd and old fashioned. A lot of distrust in the current government emerged as discussed in the next section.

[19] Andrés Manuel López Obrador (AMLO) current president in Mexico.

6.3.6. Trust

If we use this technology in Mexico would you trust the government to develop it? Or would you trust the industry?

As it was mentioned in the analysis of previous themes, there is very little trust in the Mexican government due to perceived corruption. A recent article by the media agency (Reuters, 2019) quoted a study by the anti-graft group stating that "9 out of 10 Mexicans underscored that corruption remains a problem for the country". As a result, when asked who participants trust to develop green ammonia, industry was trusted much more than the government.

While industry clearly came out as the most trusted to develop ammonia technology, it is important to note that throughout the discussions, industry was mentioned several times as the one responsible for pollution and CC. However, people would still choose them above the government because of the lack of interest in renewable energy by the current president.

FG3 was the most neutral about this topic. Though they mentioned "the industry" at first, a couple of minutes later they reconsidered their answers and were talking about maybe involving the government and suggesting that industry and government should work together. The reason for different answers between FGs might be due to the high support that the new government has from low-income families as it is the first left leaning government to be in power (Felbab-Brown, 2018).

Answers were also focused again on comparisons with Europe, and a lack of trust in the government and the industry led participants to conclude that green ammonia cannot be pursued in Mexico, but it should be done by Europe as "they are not as close minded as Mexicans" (Roxana,42). Participants chose who they would trust as soon as the question was asked, however as they discussed their opinion, every FG decided that this type of technology was better for developed countries like Europe. No other country or region of the world was mentioned when they were looking for a reference.

"You know what? in Mexico we have a very close culture, in other countries like Europe this could work out, we can't even separate our own waste to recycle, don't expect people to care about this kind of thing" (Ernesto,27)

"Investors won't invest in technologies like these ones here in Mexico, I'm sure they would go to other countries" (Lourdes,52)

"I hope Mexico could do something like this, I doubt it, but maybe one day" (Regina,29)

6.3.7. Costs

Only if the topic was mentioned; *"any new technology is quite expensive, but we don't know exactly yet how much it will be... would this be something you'll be concerned about?" would you be willing to pay a bit more to have a green energy?"*

As any new technology, ammonia as a fuel and for storage, was perceived as a "very expensive alternative". According to the "First National Survey on Energy Consumption on Mexican housing" (INEGI, 2018) only 0.25% of houses in Mexico use solar panels, so people in Mexico are not really used to alternative sources of electricity and they see this as a "luxury".

Nevertheless, participants when they were asked how much extra in their electricity bill they were willing to pay if they knew their electricity would come from a clean source the answers were very positive:

FG1: 0- "I want to help but is already too expensive"
FG2: 40% - 50% more
FG3: 30%-40% more
FG4: 100% more
FG5: 10%-15%

Differences in answers are likely related to the FG's backgrounds (Detailed in the FG Overview section *6.2.5*). FG1 was in Cancun, where the average electricity bill is very expensive due to the constant use of air conditioner. In Mexico City the average electricity bill bimonthly is $171 MXN ($10.61 USD) per house and in Cancun could be approximately over $ 1,200 (64.80 USD) (Ruiz Torre, 2016) (Expatistan, 2019)

While participants in most FGs were willing to pay more for clean energy, they were also afraid that if cost would go up then some families would not be able to pay it, which might result in electricity theft. This is a real concern in Mexico, for example Mexico's Federal Electricity Commission (CFE) has estimated that the cost of power theft rose to MXN$25.7 billion during the first half of 2018 […] the actions include the regularization of round 49,900 users who consume electric power without a contract" (Cruz Serrano, 2019).

Additionally, it is worth noting that most of the participants in the focus groups replied with high percentages about how much they are willing to pay extra on their electricity bill for green energy. These answers raise the question whether they just answered that because they felt it was the 'socially acceptable' thing to say in front of the group, whether they were seriously willing to contribute financially to clean energy generation or because the question was based on percentages and not specific amounts.

According to the report *Paying for Energy transitions: Public Perspectives and Acceptability* from (C. Demski, Pidgeon, Evensen, & Becker, 2019) participants were willing to spend more when it was displayed in percentages instead of the amount in their currency (£). "The sample was randomly split into two groups, with half asked what level of transition cost would be reasonable for the public to pay in pounds (£) and the other half asked as a percentage of their energy bill. Those asked in percentage terms indicated cost acceptance twice as high compared to those asked in pounds." (p.5)

6.4. Summary and Discussion

It is important to understand people's responses and beliefs about a new emerging technology like green ammonia to effectively incorporate their concerns and perspectives into technological development. Especially given that there is uncertainty associated with the effectiveness, cost and risks associated with new technologies, public perception studies can point to important ethical and value issues not otherwise considered (Pidgeon et al., 2012).

To this end, this chapter intended to explore people's initial associations and responses to ammonia and its possible use as an energy fuel and storage technology in Mexico, to examine people's risk and benefit perceptions of ammonia as an energy vector in the context of CC, and to explore other relevant perceptions such as views on governance of ammonia as an emerging technology. Finally, this research phase had the aim to explore public perceptions and understandings of CC and how different energy sources may contribute to carbon emissions in Mexico.

Overall, we can state that public perceptions of green ammonia are positive and perceive a number of benefits; people in Mexico are looking forward to new possibilities and are eager to learn more about this technology; this is in line with other research covered in chapter 3 which has shown people are generally positive about emerging technologies like hydrogen and nanotechnologies, if they perceive a positive societal benefit (Siegrist, Keller, Kastenholz, Frey & Wiek, 2007) (Flynn et al. 2010). It was evident that this positive initial response to green ammonia was, in part, due to it being presented as a solution to climate change. This is in line with other work which has shown that a climate change framing of technologies can produce more positive responses by the public compared to other framings (Jones, Gaede, Ganowski, & Rowlands 2018) (Corner & Pidgeon, 2015). This is more fully explored in the last chapter of the thesis.

While first associations and affective responses with the word "ammonia" were negative and indicative of specific risk perceptions around health (mentioning words like death, toxic and poison), participants still had positive reactions and this did not affect their opinion about using it as an energy fuel in the future. Participants reaction when presenting the concept of "green ammonia" was positive and despite the doubts and difficulties perceived, there were no negative comments about the technology itself, just disadvantages on an external level of the technology. As such, risk perceptions specific to the technology did not appear dominant to people's evaluation of the technology, but the context in which it is developed appears more important.

One of the most common questions and worries about the technology among participants was about how water intensive the technology would be, due to the water shortage Mexico City is facing currently. This is interesting because, subject to explain this in more detail in later chapters, when comparing this answer to experts' perceptions in previous findings, they thought public was going to be concerned about the smell, when actually this chapter shows that they are more concerned about water usage and trust to keep the technology safe (both for humans and environment) rather than the smell. This is a good example of how public and expert perceptions can differ in terms of what they consider important to consider when developing a new technology such as green ammonia.

A second concern emerged around trust, which (as discussed in chapter 3, section 3.4), is an important element for understanding public acceptability of new energy technologies. In the Mexican context, people expressed low trust and confidence in developing the technology because of low trust in the government generally and specifically around climate change issues. Participants in the focus groups tended to trust industry more than government when it comes to developing green ammonia, but ultimately concluded that neither are committed to solving the climate change problem. Participants were not asked about possibly introducing an independent regulator, although this was also not mentioned spontaneously by participants and would probably not have changed views very much (as an independent regulator cannot dictate to the government how to tackle climate change). Future research should however look further into issues of trust in different institutions in Mexico for developing low-carbon energy technologies, for example it could look at existing trust levels and how these could be improved through different actions and public engagement.

When analysing the second objective about first and spontaneous associations with topics related to green energies, one of the most relevant findings in the research was the high level of concern about CC. Climate change was introduced as a discussion topic, in part, to provide the background to why green ammonia was being developed. However, it became a more substantial discussion topic among participants than anticipated when designing the protocol. There was a feeling of desperation among participants when talking about CC; they are aware of the importance of this matter and the lack of action from people and even from the Mexican government to solve this. Nevertheless, the discussions also showed that there is still confusion amongst participants between CC and pollution. Similar confusion was noted in research carried out by (Bostrom, 1997). According to studies of lay mental models of hazardous processes "lay thinking about complex risks can be sophisticated but tends to be simpler and more general than experts' and is more susceptible to errors. For example, people often confuse global warming with stratospheric CC (at a mechanistic level) and some may attribute global warming to *pollution* generally" (p.111).

Additionally, aligned to the feeling of despair about CC, participants felt Mexico was further back in a world that is constantly changing and acting against CC. We can even suggest there was a feeling of resignation when mentioning that in Mexico this kind of actions and technologies could never be possible, mainly because of an oil refinery the new government is planning to open. For the same reason, several comparisons with Europe were made, where we observed that participants associate these countries as an example of how society should behave in respect to the environment and the impossible scenario for Mexico. It should be noted that the researcher was conducting the research as part of her PhD in the UK and as such the comparison to Europe may have been prompted by this fact.

Is important to highlight the socio-political context during the FGs, as stated in *Chapter 4*, Mexico was going through a political transition, where the new president announced the opening of new oil refineries during his term. This could have impacted the feeling of resignation among participants for the last section.

6.5. Limitations

There are some limitations to this research phase that need to be addressed. First, as it was mentioned in the methodology section at the beginning of the chapter, all FGs were carried out in Spanish to allow participants to express their ideas and feel comfortable during the session. The researcher transcribed and translated the information. Despite the fact that the researcher native language is Spanish, some of the concepts could have been lost in translation. This is explored further in the discussion chapter (*Chapter 8*) as a common limitation of cross-national studies. Due to the limited resources available, it was not possible to make use of back-translation services, however several other checks were put in place to ensure the accuracy of the translations. One, the researcher who conducted the analysis is a native Spanish speaker so was able to check her interpretations of the data and the English translations of the quotes used in this thesis. Two, one of the supervisors of this thesis is also a Spanish native speaker and checked the transcriptions for accuracy.

Second, participants were recruited through contacts in the community, whereby in each location the researcher obtained one or more contacts which later passed the invitation to other members of the same community until the desired number of participants was reached. This could have caused the age and socioeconomic background of most of the participants to be similar. Additionally, because of the recruitment strategy, participants in FG2, FG3 and FG4 were familiar with each other. This was an advantage because they felt confident and were able to speak freely, however, they may have avoided certain topics for fear of being judged by their acquaintances. The main researcher was also familiar to one participant in FG1, two participants from FG4 and one from FG5. Even though these participants are not close to the main researcher or has never discussed the technology before with them, this could have also impacted the responses by obtaining positive comments about the technology or led to participant bias – when a participant reacts purely to what they think the researcher desires (McCambridge et al., 2012). This was controlled by not interacting in a closer aspect with these participants and by highlighting at the beginning of the FGs that there were not wrong or right answers and that all points of views were welcome.

It should also be noted that the focus groups were kept short (about 1 hour) to enable participation from a wide variety of backgrounds and not overburden participants. If more time was available, it would have been possible to explore people's perceptions and reactions in more depth, provide more opportunities for participants to learn about the technology, and this enable informed opinions to emerge. Given the short time frame of the focus groups, they were only able to gather insight into people's initial reactions, associations and perceptions. This, however, is still an important element of public acceptance research especially for emerging technologies such as green ammonia, because it provides an approximation of how people might react when first confronted with the idea of the technology. This is particularly important for emerging technologies where large parts of the population is unlikely to have the opportunity to learn about the technology in-depth.

Third, as mentioned in the introduction chapter (*Chapter 1*), FGs were only performed in Mexico due to lack of financial resources which restricted the possibility to obtain data from participants in the UK. However, for the following section (phase 2, part 2) we distributed a survey in Mexico and the UK.

Chapter 7. PHASE 2.2 - SURVEYS

7.1. Introduction

This chapter is divided in two main sections: methodology and results. It begins by providing all the necessary information about the methods used to collect and analyse data for the purpose of the second phase: part two. It describes the research strategy, respondents and recruitment procedures, and consequently presents a detailed description of the questionnaire structure and the process of data analysis.

The second section describes and analyses the results obtained from the survey distributed in Mexico and the UK between May 20th and June 18th 2020. It begins with an analysis of the profile of respondents (Q.1-6) in both countries comparing it to national statistics. This is followed by a short description of first associations with the word *ammonia* (Q.7). Then, climate change perceptions (Q.8- 13) and climate change knowledge (Q.16-19) are analysed. Furthermore, the chapter presents respondents' initial responses to the idea of green ammonia (Q.19-21), followed by perceptions of risks and benefits (Q.22-26) and acceptance of ammonia projects in their country (Q.27-29).

The chapter concludes with an analysis of the role of demographics and climate change (CC) risk perception in explaining support for green ammonia technologies. Additionally, the chapter provides conclusions and limitations.

7.2. Methodology

7.2.1. Rationale

Phase 2.2 consisted of an online survey distributed in Mexico and the UK. The specific aims of this chapter are (1) to examine public responses, perceptions and understanding of ammonia in a larger, more representative sample; (2) to compare key perceptions across Mexico and the UK to gain a better understanding how the national and socio-cultural context may shape views; and (3) to explore how socio-demographic factors and climate change perceptions relate to public support for green ammonia technologies.

In prior stages we chose a qualitative approach (interviews and FGs), asking respondents to discuss their perceptions about the use of new technologies such as ammonia as an energy vector and for energy storage. In this second part of phase 2 of the research, a quantitative study took place using surveys for data gathering. The questionnaires were developed using the information collected from previous stages of the research based on perceptions from experts and the general public in focus groups, as well as previous surveys on the topic of CC. Responses from previous stages were used mainly to create questions for the section on green ammonia (see questionnaire structure in sections below). Given there is limited research on public perceptions of green ammonia, the previous expert interviews and focus group phases was useful in determining what aspects to include in the survey (e.g. in terms of perceived risks and benefits).

In comparison to qualitative methods, quantitative methods offer specific and numerical results. It provides the opportunity to analyse the relationship between different factors through a statistical approach. The clearest difference between quantitative and qualitative methodologies is their foundation (positivism vs constructivism) as it was described in *Chapter 4*. Quantitative methodology is constructed as a research strategy that emphasizes in numeric data while qualitative emphasizes in words (Bryman, 2012).

After an initial exploration of public perceptions of green ammonia through focus groups, a quantitative study (survey) was chosen to examine public perceptions in a larger sample, also including a cross-cultural component by comparing perceptions in Mexico and the UK.

This phase represents the last study of this research project, and data obtained from the surveys will be compared to findings from FGs. Finally, findings relating to the public perceptions of green ammonia will also be compared to perceptions of experts in the discussion chapter (*Chapter 8*).

7.2.2. Research Strategy

7.2.2.1. Respondents: Recruitment and final sample size

The questionnaire was distributed through online surveys using the Qualtrics survey platform in Mexico and the UK. This method is considered a useful option for public perception studies as they reduce bias and produce valid and reliable results that can be generalised (Dowler, Green, et al., 2006). Additionally, surveys will allow us to reach a wider range of the population in both countries, which is the best option for countries like Mexico which holds one of the largest populations in the world. By obtaining a larger sample than that achieved in focus groups we can gain a better indication of public perceptions and beliefs in relation to green ammonia in a more diverse sample.

Respondents were recruited through *snowball sampling*. This consists of distributing the questionnaire amongst members of the populations who are available to the researcher (Naderifar et al., 2017). For example, distributing the survey to colleagues and friends first and then asking them to pass it on to other people until subsequently a large number of respondents is reached. This type of sampling "is applied when samples with the target characteristics are not easily accessible" (Naderifar et al., 2017). Please see Appendix C.1 for information provided to recruit participants

This type of methodology was chosen due to lack of financial resources which restricted the possibility to hire an agency to obtain a demographically representative sample in Mexico and the UK. Therefore, the online survey was distributed mainly by the researcher throughout contacts in the community initially (friends, colleagues from work and family members) by social media, who then passed it on to their contacts to reach a wider population.

Even though the survey was distributed mainly through social media and people known to the researcher, the recruitment process also considered targeting people from different age groups and educational levels. This was achieved by using different social media channels - each platform was chosen to reach different demographics. Therefore we deliberately chose different channels to target the following age groups: Instagram (18-24), Twitter (18-49), Facebook (25-49) and LinkedIn (30-64); (Chenn, 2020) Through this process we were able to reach people from different demographics and asked them to share it with their acquaintances.

In Mexico, Andrea M. Guati Rojo was responsible for contacting the first sample wave. Additionally, supervisor Agustin Valera-Medina distributed the survey through his contacts in academia. For the UK, the process was slightly different, supported by both supervisors (Christina Demski and Agustin Valera-Medina) as they have both being living in the UK for several years. Please see the results section (7.3) for a detailed description of the sample obtained in both countries.

In both cases, the initial stage of recruitment occurred via email and social media, such as Facebook, LinkedIn, Twitter and Instagram, whereby respondents were informed about the survey through a link. The survey contained information about the overall project, as well as the debriefing and consent form, and how the data will be used (see *Appendix C.1.1*).

The data collection process had a total duration of four weeks. The main objective was to obtain the largest number of respondents as possible in order to achieve reliable results and representative data from each country. The expected sample size was of 300 respondents for each country in order to obtain a sample large enough for data analysis in line with the aims of this research phase. A power analysis suggested that a sample size of at least 300 per groups would be adequate for detecting small to medium size effects (Cohen, 1988) with 80% power (using the planned statistical analyses, see Table 7.1). In terms of proportion differences between countries, a sample size of at least 300 per country would provide a 5% margin of error with a 90% confidence rate, which was considered to be adequate for the research aims.

During the distribution of the survey the number of responses were analysed frequently to examine possible actions to get a higher participation rate. This process included actively looking for groups on social media or sending reminders though email and WhatsApp. Once we stopped receiving responses it was decided to close the survey and start the analysis. At the end of the data collection a total number of 357 respondents in the UK and 563 in Mexico took part.

7.2.2.2. Procedure

All communication with respondents was in the main official language of the country – Spanish in Mexico and English in the UK.

A link to the survey (powered by Qualtrics) was sent to respondents via email and social media where they were able to read the consent form prior to starting the survey. Once they agreed to participate, the survey started. At the end of the questionnaire further information was given with contact details in case respondents wanted to contact the researcher.

The overall duration of the second phase: part two was of 1 month (May, 2020 – June, 2020). The quantitative data collection began in May, 20th and was carried on through the end of June, 2020. This was followed by several weeks of analysis.

All responses were anonymous and no personal information linking the participant was kept by the researcher. Respondents were fully aware of the areas being explored and had the right to withdraw from the study at any point during the research process. Respondents were asked to give their consent in advance. Through debriefing, respondents were informed of the procedures to contact the investigator if they wished to do so (*see Appendix C.1.1*).

7.2.3. Questionnaire and structure

The questionnaire followed a similar structure from *phase 2: part 1* (FGs in Mexico), whereby the survey was divided into seven different sections:

1. Demographics
2. Perceptions of CC
3. Pro-Environmental Behaviour
4. Overpopulation
5. CC knowledge
   - Knowledge about energy sources
   - General knowledge
6. Green Ammonia
   - First associations
   - Initial responses
   - Risk and benefits
7. Ammonia in their country

Our main objective was to understand their previous knowledge and concerns about CC, to later introduce the concept of green ammonia and analyse perceptions about these new alternative energy systems.

Because this research is cross-cultural we designed the questionnaire specific for each country. Most of the questions were the same in both the Mexican and UK survey, however some questions needed to be adapted to the country context, for example questions about level of education and developing green ammonia projects.

The structure of the questionnaire is described below with the rational for each section:

<u>Introduction</u>

As a first step, respondents were presented with basic information about the survey and the requirements (e.g. 18+ and living in UK or Mexico). The consent form was adapted to Qualtrics specifying what participation would entail and the time it would take to complete the questionnaire (15 min approximately). Additionally, respondents were told that there was no right or wrong answer, that all the information provided was going to remain anonymous and that they were allowed to withdraw from the study at any time without giving a reason. After consenting, demographic questions were displayed.

7.2.3.1. Demographic profile of respondents

Basic information from respondents was requested in order to accurately describe our sample and compare data further with the information obtained. Gender (**Q1**), age (**Q2**), level of education (**Q3**), working status (**Q4**), political orientation (**Q5**) and location (**Q6**) were asked.

These questions had the objective to gather data about the respondents and create a sample profile, allowing us to obtain insights that would have been missed by only looking at the aggregate data (Dobronte, 2013). Furthermore, it allowed us to assess any bias in the sample caused by the snowball sampling technique – hence in the results section we compared the sample to the population statistics for each country.

Another important reason for gathering demographic information is to enable other research to replicate the original findings and continue similar research on the topic (Hughes, Camden, & Yangchen, 2016, p. 6). This is particularly relevant in the case of Mexico, where little research on perceptions of CC and energy have been conducted and future studies may want to replicate these findings and/or reach other population groups.

7.2.3.2. First Associations

In this section, respondents needed to answer one open-ended question "What are the first thoughts or images that come to mind when you hear the term 'ammonia' (**Q7**)?". No additional information was given beforehand in order to understand previous knowledge and familiarity about this gas. This question was included to gather initial 'top-of-mind' risk and benefit perceptions, knowledge and affective responses to ammonia.

As detailed in *Chapter 6*, , previous results from the FGs indicate negative perceptions from public when asked about ammonia as it is usually perceived as toxic, dangerous and poisonous (see *Chapter 6*). Similar answers were expected for this question.

7.2.3.3. Perceptions of climate change

Climate change is a complex phenomenon surrounded by numerous uncertainties. Understanding what needs to be achieved, how, by whom, when, with what resources, is of high importance for researchers all around world (SOAS University of London, 2009). Apart from the challenges involving technical aspects to tackle CC, social studies in this topic have been increasing exponentially. As it is essential to define and understand the problem and therefore, develop possible solutions that could lead to new policy-making and proposals for changes in behaviours and social practices.

In addition to demographic questions and first associations with the term 'ammonia', it is fundamental to examine public perception about CC and global warming. Given that green ammonia is a technology that presents an opportunity to decrease the use of fossil fuels and consequently help to slowdown global warming, it is important to understand respondents' perceptive about this topic. This section will allow us to get a more complete picture of public perceptions of CC in both countries.

Additionally, it will give us a better understanding of people's ideas behind the support or opposition for zero-carbon technologies, like green ammonia. The questions used to measure CC perception were selected from the *British Public Perceptions of Climate Risk, Adaptation Options and Resilience (RESiL RISK)* project (Steentjes et al., 2020).

In this section we included the following measures:

Belief in climate change

Q8. You may have heard the idea that the world's climate is changing due to increases in temperature over the past 100 years. What is your personal opinion on this? Do you think the world's climate is changing? – Responses were measured on a 4-point scale from *definitely not changing* to *definitely changing.*

Worry about climate change

Q9. How worried, if at all, are you about CC? – Responses were measured on a 5-point scale from *not at all worried* to *extremely worried*

Causes of climate change

Q10. Do you think that CC is caused by natural processes, human activity, or both?– Responses were measured as follows:

- Entirely by natural processes
- Mainly by natural processes
- About equally by natural processes and human activity
- Mainly by human activity
- Entirely by human activity
- I don't think CC is happening
- Don't know

Risk Perception

Q11. How serious of a threat, if at all, is CC to each of the following: *You and your family*, *UK/Mexico as a whole*, *People in developing countries*, *People in developed countries*. - Responses were measured on a 5-point scale from *not at all serious* to *extremely serious*.

Q12. How much do you think CC will harm you personally? – Responses were measured on a 4-point scale from *none at all* to *a great deal*

Responsibility

Q13. Which one, if any, of these do you feel should be mainly responsible for taking action against CC; *Industry*, *National Government*, *Society*, *Local government*, *Individuals and their families*, *Environmental groups*, *The international community*, *None of these*.

7.2.3.4. Climate change and overpopulation

One of the most interesting topics discussed in the FGs in Mexico was about overpopulation and its impact on CC. For this reason, we decided to include a question to measure people's opinion about limiting the number of children per family:

Q15*: (open-ended question)*
A study published in 2017 by the Universities of Lund and British Columbia suggested that the single most effective measure an individual in the developed world could take to cut their carbon emissions over the long term could be having smaller families (one fewer child per family) What do you think about limiting the number of children per family as a measure to tackle CC?

The study cited previously (Wynes & Nicholas, 2017) suggests that having one fewer child per family could save 58.6 tonnes per year of CO_2. However, this topic tends to be very sensitive as it is commonly believed that avoiding having children is perhaps limiting the opportunity of a better future and limiting our chances to find solution to global problems "Perhaps few kids in the next generation — including your kid, maybe! — will be the ones to figure out how to use clean energy to save the planet" (Sigal, 2020)

7.2.3.5. Knowledge about CC and Energy Sources

Our objective with this section was to analyse respondents' knowledge about low and high carbon energy sources and their views around the current impact of fuels on the environment.

Knowledge about energy sources and favourability (Q16 -17)

As a first step, different fuels and energy technologies were presented in a list format, in order for respondents to state if they thought the listed energy sources contribute to CC. Also, the option of "I've never heard of it" was available, to understand how familiar respondents are with fossil fuels and renewable energy technologies (**Q16**) in each country.

For the subsequent question, a list of 13 fuels (list below) was displayed next to the statement "To what extent, do you support or oppose the use of...?" Respondents had the option to rate these fuels on a 5-point scale from *strongly oppose* to *strongly support,* with a further answer option of *I've never heard of it* (**Q17**)

List of fuels presented to respondents:

1. Diesel
2. Gasoline
3. Coal
4. Natural Gas

5. LP Gas
6. Biofuels
7. Nuclear
8. Biomass
9. Hydrogen
10. Hydroelectric energy
11. Solar energy
12. Wind energy
13. Tidal energy

General CC Knowledge (Q18 -19)

The following two statements intended to measure factual knowledge about CC. Due to the lack of studies related to perceptions of CC in Mexico and previous results obtained in the FGs indicating low knowledge, these questions were added to cross-examine the former statement.

Six statements (Q.18-19) were presented where respondents had the option to choose between: *correct*, *incorrect* or *I don't know*. The statements were retrieved from a previous cross-cultural study about CC perceptions (Shi et al., 2016). These 6 items, were part of a three-knowledge scales that addressed three aspects of CC:

Physical characteristics (**Q18**)

1. Burning oil produces CO_2.
2. Nuclear power plants emit CO_2 during operation

Causes knowledge

3. The global CO_2 concentration in the atmosphere has increased during the past 250 years
4. The last century's global increase in temperature was the largest during the past 1,000 years

Consequences knowledge (**Q19**)

For the next decades, the majority of climate scientists expect…

5. ...an increase in extreme events, such as droughts, floods and storms
6. ...the climate to change evenly all over the world

7.2.3.6. Green Ammonia

After answering questions on CC, respondents were presented with information on green ammonia. The first paragraph was created by the researcher making sure the text was clear and as unbiased as possible.

However, we need to consider that even though the materials were designed with the aim of being as neutral as possible there is always a likelihood of a possible framing effect. The way ammonia is described can influence people's perceptions mainly because information about its future deployment was addressed without going into too much detail. Previous cross-national research assures that framing effects in new technologies to tackle CC can have an important effect on public's perception (E. Cox et al., 2020). The research cited confirms that general public's views will vary across deployment context (short-term or long-term measure) and technology type.

> **Please read the following information carefully:**
>
> Traditionally, fossil fuels have been used to rapidly match electricity supply with demand. By burning fossil fuels (fuels containing carbon), cutting down rainforests and farming livestock, humans are increasingly influencing the climate and the earth's temperature, causing what we know as *global warming*.
>
> This is why the need for a carbon-free fuel. But this is not easy, currently, just a few fuels exist with no carbon (i.e. hydrazine, hydrogen sulphide, ammonium nitrate, ammonia etc.). Research indicates that amongst these, **hydrogen** and **ammonia** are the simplest and most promising.
>
> Hydrogen is an excellent zero-carbon fuel to help reduce greenhouse gas emissions. However, due to its chemical composition, shipment for long distances and storage for long times present a lot of challenges. Another way to use hydrogen is through ammonia.
>
> Below we are going to present information about how ammonia fuel could be produced and utilised as an energy carrier and for energy storage

The text starts by providing a general idea of the impact of humans on CC and how this plays a significant role specially when burning fossil fuels. Consequently, we stated the need for a zero-carbon fuel to tackle this problem and describing the possible role of hydrogen. We mentioned broadly the properties of hydrogen as a carbon free fuel and consequently that this element was found in ammonia. Hydrogen was mentioned because is better known by people and it is getting more relevance in the energy sector (Ricci et al., 2008b).

The summary paragraph was accompanied by a graphic (see *Appendix C.3*). Respondents were then asked an open-ended question: "what thoughts or images came to mind when reading this information about green ammonia?" (**Q20**) Respondents were asked to enter their thoughts in a text box. This was followed by a close-ended question: "How do you feel about green ammonia?" (**Q21**). Respondents were asked to answer on a 7-point scale from *extremely negative* to *extremely positive*. This question was included to measure initial affective responses to green ammonia, as affective aspects of technology appraisal are considered important for technology acceptability (Huijts et al., 2012).

These two questions also provided information about how respondents perceived this technology and how their perception about green ammonia might differ from Q1 at the start of the survey (as a result of receiving further information about green ammonia and its potential development to address climate change).

Risk and Benefits

After understanding their first general perceptions of the technology, we decided to analyse more specific aspects of it, such as perceived risks and benefits because these have also been found to be particularly important for understanding attitudes and perceptions of emerging and low-carbon technologies (Upham et al., 2015; Huijts et al., 2012). Firstly, four benefits were presented and respondents were asked to indicate on a 5-point scale how positive they consider them to be (from *not at all positive* to *extremely positive*) **(Q22).**

1. When ammonia is used to generate energy, it is converted into water and air so it would not contaminate the environment
2. Infrastructure to use ammonia is already in place around the world
3. The penetrating smell of ammonia is a useful way to detect any gas leak
4. Animal waste, which contains ammonia, could be utilized to create energy instead of polluting soil and water

When presenting risks, a similar list with five statements was offered where respondents needed to rate on a 5-point scale "To what extent are you worried about the following risks" (**Q23**)- *not at all worried* to *extremely worried*.

1. Ammonia is a toxic gas that when inhaled in large concentrations can cause burns in eyes and mouth
2. As a fuel, if ammonia is not burned properly, NOx particles (a type of greenhouse gas) can be released, contributing to CC.
3. Ammonia technology to store and generate energy would need large investments to commercialize, this might imply higher prices in electricity.
4. Ammonia has a very unpleasant smell.
5. Ammonia technology is water intensive so it would need to be developed in areas with easy access to water.

Consequently, we asked "On the whole, how acceptable or unacceptable are the risks of green ammonia to you? (**Q24**) where again respondents had the option to rate their risk acceptability on a 5-point scale from *very unacceptable* to *very acceptable*. For the last two questions in this section we asked "Do you think there are more risks or benefits from green ammonia" (**Q25**), three options were available:

1. The risks outweigh the benefits
2. The risks and benefits are about the same
3. The benefits outweigh the risks

Then a possibility to add any additional concern was added at the end with an open-ended question asking "Do you have any concern about ammonia"? (**Q26**)

This section was important for the analysis as it gave us the basis to understand the risk and benefit perception of ammonia-based technology in two different countries. For any new technology, the public perception of risks and benefits will depend on several factors; it has been acknowledged that when talking about risks people tend to construct their opinion about hazards based on psychological factors rather than a technical risk study provided by experts (Frewer, 1999).

7.2.3.7. Ammonia in the UK (or Mexico)

Our aim for this last section was divided in two. First, the aim was to understand and analyse public perceptions about the implementation of ammonia energy technologies in their countries (Mexico or the UK) and second, to measure levels of trust in different institutions (government and industry) to develop this technology. Therefore, different results were expected in each country as trust in the government and industry are expected to be dependent on the country context (Paul Slovic, James Flynn, C. K. Mertz, Marc Poumadère, & Claire Mays, 2000).

This section started by asking if respondents would support or oppose the use and development of green ammonia technologies in their country as a way to reduce carbon emissions (**Q27**). Responses were based on a 5-point scale from *strongly oppose* to *strongly support*.

After analysing the level of support in each country we wanted to understand how feasible respondents thought this kind of projects were in their countries. Therefore, they were asked "How feasible do you think the development of this kind of project (e.g. ammonia technologies) might be in the UK/Mexico? (**Q28**)". They needed to rate their opinion on a 5-point scale from *definitely not feasible* to *definitely feasible*.

The survey concluded by analysing who would they trust to regulate this technology. Respondents were asked to choose from four different options: 1. *Government*, 2. *Industry*, 3. *Both* or 4. *None*.

Results from previous findings in Mexico (FGs) indicate a lack of trust in the government. The aim of this last question is to compare the results with previous findings in Mexico and between the two countries. Results are expected to contrast between countries. Data obtained from FGs in Mexico show a high trust in the industry to develop new technologies, whereas a recent report suggests that British perceive industry as "essentially self-serving and just acting in their best interests" (Wisniewski, 2020).

7.2.4. Data Analysis

As mentioned before, surveys were distributed online powered by Qualtrics. All data was analysed using SPSS version 26. Responses were screened for abnormalities (e.g., indicating a different country) and filtered to only respondents with a 100% completion progress of the survey.

We received a total of 1,350 responses, 511 for the UK and 839 for Mexico. However, a large number of responses (151 for the UK and 274 for Mexico) had less than a 100% completion rate within Qualtrics, which suggests respondents dropped-out of the survey before completing it. In line with ethical guidelines, these respondents were not included in the data analysis. Five additional respondents were excluded (2 in the UK survey and 3 in the Mexico survey) who indicated a region different from UK or Mexico. In total, we took into account 920 responses for this analysis, 357 for the UK and 563 for Mexico.

Most of the questions in the survey were close-ended multiple choice questions, consisting predominantly of Likert-scale questions. The choices were designed to range from negative to positive (e.g. strongly disagree to strongly agree) with a neutral option in between. Questions were designed to be five- or seven-point scale. High scores were used to indicate agreement or higher concern, support, favourability etc; where necessary items were re-coded to reflect this.

Using this type of question with multiple scale options we were able to get a comprehensive view of respondents' perception, level of disagreement/agreement and even neutral perspective about different topics (Typeform, 2020). The survey instrument was shared with the Environmental Psychology group (Risk Group) at Cardiff University to be tested and reviewed by different researchers experienced in survey research to ensure the validity of the Likert-scales and other multiple-choice questions.

Data gathered from the survey was analysed using a range of statistical methods (see *Table 7.1*). This study applied mainly basic statistical approaches such as frequency distributions, descriptive statistics, t-tests and z-tests.

Independent t-tests were used to test for significant differences between measures, post-hoc comparisons were used with Bonferroni corrections (M. Evans, 2020). For most of the questions all the percentages, means and values are detailed in the appendix section as stated in the results section below (7.3). When making comparisons between countries, covariates including age, education and political orientation were included to control for their influence. When these covariates significantly influenced the findings, this is stated in the relevant text. If the covariate analysis did not produce different findings, the simpler t-test finding is reported with appropriate effect sizes.

Advanced methods such as linear and multiple regressions were used at the end to understand how socio-demographic variables and climate change perceptions are related to support for green ammonia technologies.

For open-ended questions, most common answers were identified and divided into categories. Consequently, each category was then split by topics providing a code for each of these. All codes, descriptions and values are detailed in the appendix section of the results chapter.

Table 7.1. Analysis description by section

	Section	Question	Tests Performed
1	Demographics	1 - 6	Frequency/percentages/t-test
2	Perceptions of CC	8-13	Percentages/t-test/z-test
3	Overpopulation	15	Percentages/t-test
4	CC knowledge	16-19	Percentages/ t-test /chi-square
5	Green Ammonia	7; 20-26	Frequency/percentages
6	Ammonia in their country	27 - 29	Frequency/percentages/linear and multiple regression

7.2.4.1. Demographics (Q.1 -6)

For the first section of demographics, gender (Q.1), age (Q.2), level of education (Q.3) and working status (Q.4), we performed a basic analysis of frequencies and percentages which allowed us to compare and identify significant differences between countries. Additionally for Q.5 (political orientation) we used an independent t-test to compare respondents' political orientation. Results from these tests were also compared against national data from each country to understand if the obtained samples were representative of their countries.

The last question of this first block was Q.6 on location. An open-ended question was used to identify in what region respondents live. Both countries were divided into different areas according to the political division in each country (UK in 12 and Mexico in 5). Each of these areas were assigned a value which allowed us to quantify the data and obtain a precise number of respondents living in a certain location. As it can be observed in *Table 7.2*, below, codes valued from 1-18, *1* meaning blank answers or don't know, *2- 13* to represent the UK and *14 to 18* to represent Mexico.

Table 7.2. Values per region in each country (Q.6)

Value	Code	Region
1	Nothing/Don't know	
	United Kingdom[20]	
2	Scotland	
3	Northern Ireland	
4	Northeast	*Co Durham, Northumberland, Tyne & Wear and the Tees Valley*
5	Northwest	Lancaster, Cheshire, Manchester *Cheshire, Cumbria, Greater Manchester, Lancashire and Merseyside.*
6	Yorkshire and the Humber	*North Yorkshire, West Yorkshire, South Yorkshire, East Riding, North Lincolnshire and North East Lincolnshire.* Hull
7	East Midlands	*Derbyshire, Leicestershire, Lincolnshire, Northamptonshire, Nottinghamshire and Rutland.*
8	West Midlands	*Birmingham, Herefordshire, Shropshire, Staffordshire, Warwickshire, West Midlands, and Worcestershire.*
9	Wales	
10	Southwest	*Cornwall, Devon, Dorset, Gloucestershire, Somerset, Wiltshire, and the Isles of Scilly.* Bristol
11	Southeast	*Berkshire, Buckinghamshire, East Sussex, Hampshire, the Isle of Wight, Kent, Oxfordshire, Surrey and West Sussex*
12	East of England	*Bedfordshire, Cambridgeshire, Essex, Hertfordshire, Norfolk, and Suffolk.*
13	Greater London	
	Mexico [21]	
14	Northwest	Baja California, Baja California Sur, Chihuahua, Sinaloa y Sonora
15	Northeast	Coahuila, Durango, Nuevo León, San Luis Potosí y Tamaulipas
16	West	Aguascalientes, Colima, Guanajuato, Jalisco, Michoacán, Nayarit, Querétaro y Zacatecas
17	Centre	Distrito Federal, Estado de México, Guerrero, Hidalgo, Morelos, Puebla y Tlaxcala
18	Southeast	Campeche, Chiapas, Oaxaca, Quintana Roo, Tabasco, Veracruz y Yucatán

7.2.4.2. Perceptions of climate change

This section was composed of 6 different questions (Q.8-13), all of them multiple choice questions. Descriptive statistics in the form of percentages are reported alongside the results of t-tests for questions 8, 9, 11 and 12. This type of analysis is used to determine the difference between the means of two independent groups (Lund Research Ltd, 2013). Through this analysis we were able to understand significant differences between Mexico and the UK respondents regarding the believe that the world's climate is changing (Q.8), concern about CC (Q.9), seriousness of CC (Q.11) and how much CC is going to harm them in the future (Q.12). For Q.11 four t-test were performed simultaneously, therefore a Bonferroni correction was applied to control for Type I error.

[20] Biles, 2019; (Netherlands Business Support Office)
[21] Montalvo, 2013

For questions 10 and 13, z-tests were performed to compare proportions between countries. For Q.10 we wanted to compare perception of cause of CC and in Q.13 who is perceived to be responsible to take action against CC.

7.2.4.3. Overpopulation

This section was formed of one question (Q.15) where respondents were presented with a paragraph regarding overpopulation and the idea of having "*one fewer child per family as a measure to tackle CC*" (see section 7.2.3.4 for full text and description). Respondents were asked to rate this statement on a 5-point scale (1-Strongly disagree to 5-Strongly agree).

In order to analyse the results, as a first step we obtained the percentages to acquire a broad idea of respondents perception about the topic. Consequently, a t-test was performed to determine if there was a significant difference between the mean perception in both countries.

7.2.4.4. Climate change knowledge

This topic was divided in two blocks of questions: knowledge about energy sources (Q.16-17) and general CC knowledge (Q18-19). The first block of questions was related to knowledge about energy sources, a list of 13 energy alternatives was displayed (see section 7.2.3.5 for the full list).

First, respondents were asked to indicate if they believed the listed energy sources contribute to CC (Q.16) and secondly, indicate to what extent they support or oppose their use (Q.17). For Q.16 only percentages were obtained and then displayed in a graph per country. A chi-square analysis was conducted to examine differences across countries. For Q.17 percentages and a t-test were performed, again a Bonferroni correction was applied to the analysis.

Consequently, the second block of questions intended to measure general CC knowledge. For both questions we obtained percentages and a chi-square test was conducted to compare across countries. Q.18–19 consisted of six statements for respondents to indicate if they were *correct*, *incorrect* or *don't know* (see section 7.2.3.5 for full description of the scenarios).

7.2.4.5. Green Ammonia

This section consisted of different analysis methods to examine public perceptions of ammonia and green-ammonia technologies (Q.7, 20-26). It was also divided in two blocks. First initial perception of ammonia and green ammonia followed by perceptions of risks and benefits.

For the first block, one open-ended question was displayed at the beginning of the survey asking to list the first thoughts or images that come to mind when hearing the word 'ammonia' (Q.7). Similar to the previous open-ended question for region, we created different values for each group of words.

This process started with all the responses being scanned to get a general idea of the most common answers. Next, different categories were created to summarise these responses (see *Table 7.3*). Once we established values for each category/coding then each of the responses from respondents were given a value depending on the answer (new values were created if needed). This allowed us to quantify the answers and measure most common responses in terms of percentages.

Table 7.3. What are the first thoughts or images that come to mind when you hear the term 'ammonia'? (Q.7) [22]

Value	Coding	Description
1	Nothing/don't know	Don't know, unsure, NA, nothing, none/ have no idea/nothing comes to mind
2	Poison	Any mention of ammonia being poison, toxic, an acid, corrosive
3	Smell	Responses about the smell. Penetrating smell/smells horrible /unpleasant
4	Safety	Any mention of not being safe/dangerous or bad for humans
5	Chemical	Any mention of ammonia chemical properties. A chemical/ nitrogen/hydrogen/NH3/NH4
6	Cleaning product	Any mention as a product for cleaning/bleach/disinfectant
7	Urine/manure	Any mention of urine/faeces/manure/animal or human waste/yellow liquid
8	Pollutant	Mentions of an impact to the environment pollutant/ bad for the environment
9	Death	Death/killing/kidnapping/bombs/blood
10	Fuel	Energy/clean fuel
11	Industry	Fertilizer/refrigerant
12	Other products	Hair products/painting/tanning
13	Negative	Open concepts expressing negative feelings concepts like terrible/bad
14	Substance	Broad idea of ammonia such as gas/substance
15	Confusion with other chemicals or fuels	"kitchen gas" (natural gas)/ "swimming pool" (chlorine)/ "Biodigester" (Biofuels)
20	Other	Any code that does not fit elsewhere.
99	Misc	Responses that don't make sense, reword question, do not answer question.

Later in Q.20 the concept of *green ammonia* was introduced to respondents through an infographic (see *Appendix C.3*). Similar to the question on initial perceptions of ammonia (Q.7), we intended to gather first associations with the concept of *green ammonia* through an open-ended question. Again, codes were created and values were assigned (see Table 4). We wanted to understand the difference between initial perception of *ammonia* and perception of *green ammonia* after presenting a brief explanation to respondents. Responses again were captured through percentages to indicate the proportion of the sample that mentioned a particular topic.

[22] Due to lack of resources, inter-coder reliability of the codes for Q7 and Q20 was not checked.

Table 7.4. "Please tell us what thoughts or images came to mind when reading this information about green ammonia?" (Q.20)

Value	Coding	Description
1	Nothing/don't know	Don't know, unsure, NA, nothing, none/ have no idea/nothing comes to mind
2	Poison	Any mention of poison, toxic, acid, corrosive
3	Smell	Responses about the smell/ penetrating smell or odour
4	Safety/dangerous	Any mention of not being safe/dangerous or bad for humans
5	Solution/alternative	Reference as "the solution"/promising/an alternative/progress/potential
6	Novel concept	New for me/ I've never heard about it before/ I didn't know about this/surprised/wow
7	Cost	Mentions of being costly, expensive
8	Pollutant	Mentions of a negative impact to the environment pollutant/gas bad for the environment
9	Complex/Confusing	Any reference to being confused, puzzled, too complicated
10	Need more information	Any mention of needing more information. Queries about what it is and how it works
11	Water	Any reference to water, water quality, shortages
12	Positive for environment	Good option for the environment/good green fuel/less pollution
13	Negative	Open concepts expressing negative feelings concepts/terrible/bad
14	Positive	Open concepts expressing positive feelings. Sounds promising/looks like a good idea /interesting/great idea/amazing/impressive/beneficial
15	Sceptical	Weird, I don't believe it. Not sure it can work. It will end up being like any other technology
20	Other	Any code that does not fit elsewhere. Important/security
99	Misc	Responses that don't make sense, reword question, do not answer question.

After the infographic was presented, respondents were asked to rate on a 7-point scale (from 1-Extremely negative to 7- Extremely positive) how they feel about green ammonia (Q.21). Means were compared between countries while percentages were used to detail information.

For the second block of questions, perception of risks and benefits was analysed. Respondents were given a list of benefits and risks, presented in order for them to rate how positive or worried they feel about these.

This part of the survey consisted of five questions. All of them were analyse through comparing the means between countries. For questions 22-24, t-tests were performed afterwards to analyse possible significant differences between countries. For question 25, *"Do you think there are more risks or benefits for green ammonia?"* no t-test was performed but percentages were used to compare answers between countries.

To conclude this section, respondents were asked about additional concerns of green ammonia. The same process for open-ended questions was followed assigning codes and values to each answer to later quantify results through percentages.

7.2.4.6. Ammonia in their country

For this last topic the most important question was asked "*Would you support or oppose the use and development of green ammonia technologies in your country as a way to reduce carbon emissions?*". Firstly, percentages were obtained to indicate the level of support and opposition for green ammonia in each country.

Furthermore, advanced methods including linear and multiple regressions were used to illustrate how a series of independent variables (demographics, CC worry, CC threat or perception of risk and benefits) are related to the dependent variable (support for green ammonia technologies). In order to perform these tests, variables were coded to gain further insight and a reliable understanding of the correlations between them. See section 7.4 for specific details.

According to (Owuor, 2001) it is important to take into consideration two aspects when performing multiple regressions on Likert-type questions. Firstly, few Likert-point scales could result in large biases, therefore it is recommended to use questions with more than four Likert scale points. Secondly, to obtain reliable data the survey sample size is recommended to be higher than 300 respondents. Both points mentioned before were satisfied in this study; Likert scales used were between five and seven scale points and the smallest sample size is 357.

For the last question, a similar analysis was followed. Respondents were asked "*If we use this technology in the UK, who would you trust to regulate it?".* Further analysis was performed to understand the relationship between trust and support from green ammonia technologies. A regression analysis was carried out to provide insights about a possible significant relationship between these two variables.

7.3. Results

This section presents the results from the surveys distributed in Mexico and the UK, between May 20th and June 18th 2020, as part of the second phase of the research (Phase 2: Part 2). The analysis of the results are presented in 7 different sections covering 12 main topics:

1. Demographics (Q.1- 6)
2. Perceptions of CC (Q.8 – 13)
3. Overpopulation (Q.15)
4. CC knowledge
   - Knowledge about energy sources (Q16 -17)

- General Knowledge (Q18 -19)

5. Green Ammonia
   - First associations (Q.7)
   - Initial responses (Q.19 -21)
   - Risk and Benefits (Q.22 -26)
6. Ammonia in their country´ (Q.27 – 29)

It begins with an analysis of the profile of respondents (Q.1- 6) in both countries comparing it to national statistics, details about the location of respondents are described in Appendix C.5c. This is followed by a short description of first associations with the word *ammonia* (Q.7). Third, CC perceptions (Q.8- 13) and CC knowledge (Q.16-19) are analysed. Furthermore, the chapter presents respondents' initial responses to the idea of green ammonia (Q.19-21), followed by perceptions of risks and benefits (Q.22-26) and acceptance of ammonia projects in their country (Q.27-29). Lastly, the chapter presents the conclusion and limitations of all the results obtained from the survey.

7.3.1. Demographic profile of respondents

Table 7.5 summarizes the demographic characteristics of respondents in the survey in Mexico and the UK, comparing them to national data from each country. This comparison enables an evaluation of potential bias in the samples and shows to what extent the sample may not be representative of the country population. Any potential bias will be considered when analysing the findings from this dataset.

Official national data suggests that both countries currently have a similar female/male ratio in their population. Results obtained from the survey confirm that neither Mexico nor the UK sample were representative of the country in terms of gender. In the UK the sample got a clear higher female participation in the survey. Whereas in Mexico the sample was slightly more balanced than the UK but still more female respondents than males took part in the study. Therefore, from data obtained in this first section we can state that the survey distributed in the UK and Mexico does not fully represent the gender balance in both countries.

According to numbers from Statista, the total UK population in 2019 was 66.44 million, 50.90% (33.82 million) were female and 49.1% (32.98 million) males (Clark, 2020). In the survey, results present a different distribution of 67.2% females and just 30% males. In the case of Mexico, population reached 129.19 million (The World Bank, 2019b), 51% (63.95 million) female and 49.2% (61.36 million) male. In the survey, female respondents accounted for 56.8% of the respondents where male 42.8%.

Survey results illustrate that in both countries most of the respondents were between 25-34 years old (UK 33.1%, Mexico 40.5%), this result is in line with data obtained from Mexico about median age which is 28.6 years (IndexMundi, 2019). However, for the UK the current population is older than respondents in our survey, with an average age of 40.1 years (Plecher, 2019), which means that age is not representative to the British population. Nevertheless, it is important to note that if we have a look beyond median age and we focus on age groups, neither the UK nor Mexico samples are representative to the population (see *Table 7.5*).

Regarding education level, both samples had a similar education level. Mexican respondents had a slightly higher education level profile than respondents from the UK with more people achieving a university degree or above. Numbers indicate that the UK had 79.9 % respondents with this profile and Mexico 88.1%. Even though samples between countries are similar, neither of the results represent the population of their countries, however the sample of the UK is closer to national statistics.

According to the national newspaper *El Financiero* (Usla, 2019) citing data from the National Institute of Statistics and Geography (INEGI), Mexico only reached an average educational level of first year of high school (2018), meaning that most students leave school at around 16 years old. In the same line, the newspaper *Sin Embargo* reported that 29.5% of the total population in Mexico has a degree equivalent to a GCSE O-level (Redacción, 2018). This information clearly contrasts with the information gathered from the survey, where this level of education just represents less than 1% of the respondents. Therefore, the Mexican survey sample has a much higher education level than the Mexican population.

On the other hand, UK results are slightly more similar to the national statistics, according to the Office for National Statistics 42.2% of the population hold a first-degree qualification from which 22% holds a masters taught qualification (ONS, 2017).

Table 7.5. Demographic information for respondents in Mexico and the UK for Phase 2: Part 2.

	P.2.2 Survey UK (N= 357)	**National UK data**	**P.2.2 Survey Mexico (N= 563)**	**National Mexico data**
Gender				
Female	67.2%	50.9 %	56.8%	51.1 %
Male	30%	49.1 %	42.8%	48.9 %
Other	2.2%	-	*	-
Prefer not to say	Below 1%	-	*	-
Age				
- 18	-	17.9% [23]	-	27.4%[24]
18 - 24	5.6%	11.8%	10.3%	18%
25 - 34	33.1%	13.5%	40.5 %	15.1%
35 - 44	18.2%	12.5%	23.3 %	14.1%
45 - 54	22.1%	13.8%	10.7%	10.8%
55 - 64	14.3%	11.9%	11.4%	7.3%
65 +	6.7%	18.3%	3.9%	7.3%
Median/Mean age	35- 44 years	40.1 years	25-34 years	28.6 years
Level of education				
Postgraduate degree (MSc, PhD)	49.9%	31.5%[25]	34.5%	18.6%[26]
University degree (BA, BSc)	30.0%		53.6%	
Professional qualification[27]	5.9%	10.7%	N/A	
Trade School	1.1%		3.2%	
A-level or equivalent [28]	6.2%	22%	6 %	21.7%
GCSE O-level [29]	3.4%	20%	*	23.7%
Still studying	2.2%	-	1.8%	15%
No academic or professional qualifications	1.4%	9.25%	-	20.4%
Working status				
Employed full time	55.2%	45%[30]	63.2%	50%[31]
Employed part time	13.2%	16%	7.8%	4.2%
Unemployed	4.2%	3%	4.6%	2%
Looking after house/children	2.2%	-	4.4%	-
Retired	8.7%	20%	4.8%	5.6%
Student	11.2%	16%	10.7%	40%
Other	5.3%	-	4.4%	

*Below 1%

[23] ONS, 2018
[24] García, Muñoz Oliveira, 2018
[25] Labour Force Survey, 2019. The 65% missing corresponds to "other/don't know" answers
[26] INEGI, 2015
[27] This level was not included in the Mexican survey
[28] Highschool in Mexico
[29] Secundary School in Mexico
[30] Clegg, 2018
[31] STPS, 2020; INEGI, 2020a

When analysing working status, both countries had similar results with a high number of respondents working full time (UK 55.2%, Mexico 63.2%). However, in the UK, the second highest proportion stated that they were in part-time employment (13.2%). In the Mexican sample, the second highest proportion were students (10.7%). An important difference to notice is the percentage of respondents that were retired in the UK (8.7%) compared to Mexico (4.8%).

As previously stated, respondents from Mexico hold a higher educational level than the average population in this country, this is also evident at analysing working status. As most of the people that participated in the survey hold a first-degree qualification, the working status goes in parallel with these results and the survey shows that in Mexico 63.2% of respondents were employed full time, when in reality Mexico is below the average of the OCDE countries (OECD, 2017a). Official data shows only a 3.1% rate of unemployment in the country (Información Dinámica de Consulta, 2020), however, 56.1% of the full-time employment numbers is under a scheme called "informal working status" (INEGI, 2020) which refers to "any work that is done without having the protection of the legal or institutional framework"(OIT Oficina Regional para América Latina y el Caribe, 2007), only 4 out of 10 Mexicans hold a formal full-time employment (Valadez, 2019). This is not represented in our sample for Mexican respondents.

In contrast, the UK sample is more representative of the UK population. In 2019, the UK reported 76.1% of people in employment (Office for National Statistics, 2020). If we take under consideration that 55.2% of our respondents were employed full time and 13.2% part time, then we can assume that this data is closer to the official information with 68.4%.

7.3.1.1. Political orientation

An independent-samples t-test was conducted to compare the political orientation between countries indicating a significant difference between them; $t(909) = 12.833$, $p < .01$, two-tailed. The question required respondents to rate their political orientation from 0-10 (0=left 10=right). Findings suggested a higher score for Mexican respondents ($M = 5.69$, $SD = 2.26$) implying that respondents from this country are more neutral with a slight tendency to support right-wing parties. On the other hand, respondents from the UK were clearly leaning more to the left ($M = 3.77$, $SD = 2.19$) - see *Figure 7.1*.

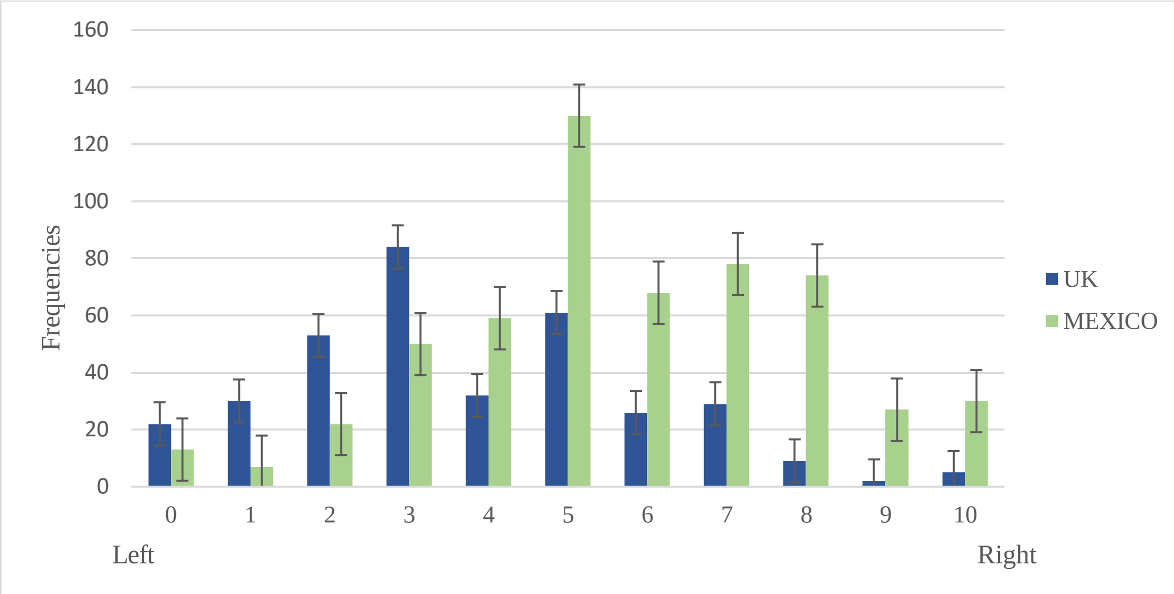

Figure 7.1. Political Orientation from respondents in Mexico and the UK (0=Left, 10=right). [32]
Error bars represent ±1 standard deviation.

These results are not representative to the profile of neither country, where the population political orientation is in reality the opposite from the sample. While the sample in Mexico is balanced with a slight tendency to the right, the country's government is held by MORENA, a left-wing party in power since 2018 with an overwhelming victory in the country with more than half of the votes (BBC News, 2017). In the UK, the party in power since 2010 has been the Conservative Party (centre-right wing), which is the opposite to results shown in our survey leaning to the left.

One possible explanation for these results is the link between level of education and political orientation in each country. According to (Curtis, 2017) "the more educated a person is, the more likely they are to vote Labour or Liberal Democrat" in the UK, this information goes in line with data from Ipsos MORI, which determined that a larger number of people in the UK with a degree or higher voted Labour (centre-left party) in 2019 elections. For Mexico is the exact opposite, according to information from the report of (México ¿cómo vamos?, 2018) the cities with higher educational level compared to the national average, voted for a right-wing party in the past 2018 election.

7.3.1.2. *Sample profile summary*

Comparison between samples

The Mexican sample is slightly more balanced in terms of gender than the UK with just a slightly higher female participation compared to men (F = 56.8%, M = 42.8%). Most of the respondents were between 25 and 34 years old, which indicates a younger sample compared to the UK. The majority holds a university degree (53.6%) and works full time (63.2%). When asking about political orientation they placed themselves in a right-wing spectrum (M = 5.69, SD = 2.26).

On the other hand, within the British sample, a high number of respondents were females (67.2%) with an average age of 35-44 years old. The educational level amongst respondents was higher than in Mexico, with a majority holding a postgraduate degree (49.9%) and working full time (55.2%). An important difference to notice is the percentage of respondents that were retired in the UK (8.7%) compared to Mexico (4.8%). On the contrary to the Mexican sample, respondents in the UK indicated a more left-wing political ideology (M = 3.77, SD = 2.19).

Comparison against national data (ND)

As a summary (*see Table 7.6*) we are going to describe below the demographic characteristics of the survey samples compared to the national data from each country. At presenting this comparison we can evaluate potential bias in the samples and present to what extent the sample may or may not be representative of the country population in terms of gender, age, education level, working status and political orientation.

Table 7.6. Comparison against national data, indication if it is representative or not.

	UK	**Mexico**
Gender	Non-representative	Close to representative
Age	Non-representative	Close to representative[33]
Educational level	Non-representative	Non-representative
Working status	Close to representative	Non-representative
Political orientation	Non-representative	Non- representative

Mexico

The results obtained from the survey confirm that respondents are close to representative of the country in terms of gender and age. Currently the country has a similar female/male ratio in the population with an average age of 28.6 years old. This data is in line with the survey sample, male/female participation was similar and the median age of respondents was 25-34 years.

[33] This comparison was against median age, if we compare national data against each age groups, neither the UK nor Mexico samples are representative to the population

However, education level and working status were not representative of the Mexican population. In the sample, Mexican respondents have a higher education profile and a higher percentage of respondents report working full time compared to the national data. 88.1% of survey respondents hold a university degree or above compared to only 18.6% of the population in Mexico with studies above high school, 71% of respondents work full/part time compared to 54.2% from the national data.

Political orientation was not representative either, while the sample reflected a central (slightly to the right) political tendency, the latest national poll at writing these results shows that a majority supports the current government in power held by a left-wing party (Redacción, 2020).

UK

In terms of gender and age for the British population, the survey sample was not representative to national data, with a higher female participation compared to the national statistics (ND: 33.8%, survey: 67.2%) and with a younger sample participation (25-34 years) compared with the national median age (40.1 years).

In terms of education level, the sample was not representative to the population. The survey sample had more respondents with a higher educational attainment (79.9% university degree or above) than the population. Nevertheless, we can state that UK results are slightly more similar to the national statistics than the Mexican sample.

When analysing working status, the UK sample is close to representative of the population, with a high percentage of respondents working full/part time 68.4% similar to national data (76.1%). An important difference to notice is the average of respondents that were retired in the UK (8.7%) compared to Mexico (4.8%).

When analysing political orientation, results from the survey show the opposite from the national data. British respondents claimed to support left-wing parties when the party in power since 2010 is the conservative power (centre-right wing),

7.3.2. CC perceptions and environmental behaviour

As mentioned in the previous methodology section, CC perception was measured and analysed using six different questions throughout the survey. Results were very similar amongst countries, for the first question in this block (Q.8) scores indicated that both countries believe the climate is definitely changing (UK 88.7% and Mexico 95.7%). An independent sample t-test shows that this belief is significantly greater in Mexico

(M = 3.94, SD = .287) than in the UK (M = 3.88 SD = .341); t(914) = 2.944, $p < .01$; Cohen's $d = .2$, two tailed.

Similarly, Mexican respondents were slightly more concerned about climate change (M = 3.83, SD = 0.771) than UK respondents (M = 3.76, SD = .969); $F(4, 905) = 8.715$, p < .01; partial $\eta 2= .01$[34]. Nonetheless, in absolute terms, both countries expressed relatively high concern about this subject. In Mexico, 68.2% stated to be extremely or very worried about CC and in the UK this was 60.9% (*see Figure 7.2*).

Results from the UK sample are in line with conclusions drawn by the BEIS Energy and Climate Public Attitudes Tracker (BEIS, 2020) indicating a high concern about CC in the UK. Although our results show a higher concern (60.9%) compared to the national representative data (40%), we need to consider that our sample is not representative of the population but still indicates that a majority of respondents feel very or extremely worried about this topic.

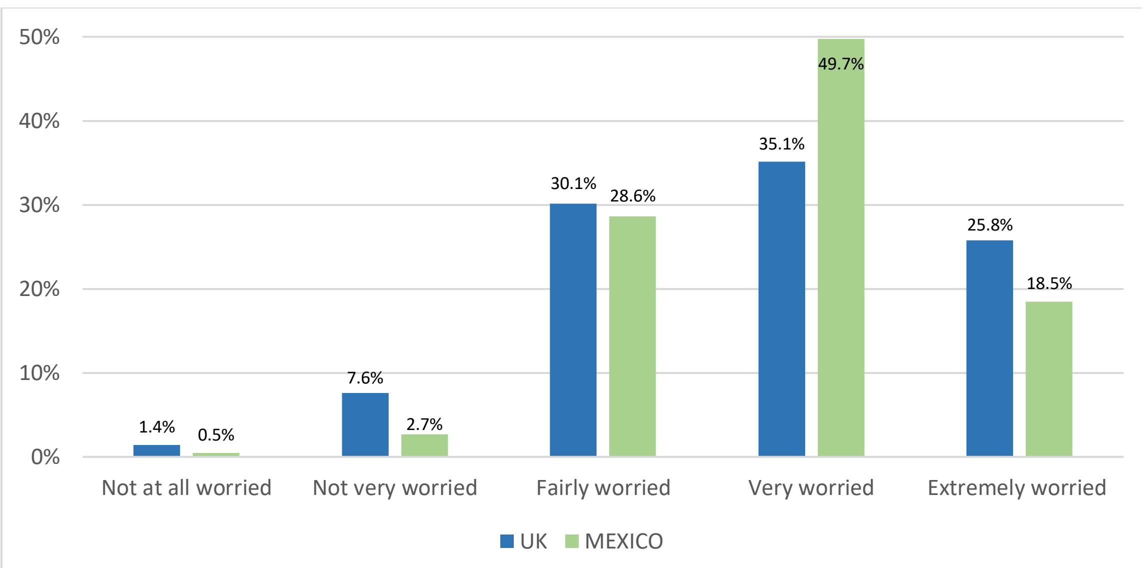

Figure 7.2. Level of concern about CC from the sample from Mexico and the UK (percentages).

Similar to previous results, both countries show comparable perception about the cause of CC. In the Mexican sample, 81.4% of people believes that CC is entirely or mainly caused by human activity and in the UK 84.1% is in line with this idea. A z-test established that there is not a significant difference between countries $z = -1.078$, $p = .280$. However, there is a significant difference between Mexico (0.9%) and the UK (2.5%) respondents believing that CC is caused entirely or mainly by natural process ($z = 1.973$. $p = .048$). Nonetheless, in both countries CC scepticism appears to be very low.

[34] When age, education and political orientation are not included as covariates, this difference is not significant.

7.3.2.1. Seriousness of CC

So far, results from the survey have indicated similar perceptions of CC in both countries. Most of the respondents from Mexico and the UK consider the world's climate to be changing, reported to feel extremely or very concern about CC and believe it is caused entirely or mainly by human activity.

Nevertheless, when asked about the seriousness of CC (Q.11), there were significant differences between countries on most questions (see *Table 7.7*). From the results of the first questions about seriousness of CC for "You and your family" and "UK/Mexico as a whole" we can state that the UK has a lower risk perception for themselves and their country than the Mexican sample. This is also evident when asking about "developed countries" where the seriousness was perceived to be lower by the UK sample compared to Mexican respondents (*see Figure 7.3*).

Table 7.7. Independent t-test for Q.11.
Bonferroni correction to $p < .012$. Mean and SD presented in the figure 7.3 below.

How serious of a threat, if at all is CC to each of the following:	**Independent t-test** (two-tailed)
You and your family	t(917) = 9.418, $p < .001$, Cohen's $d = .64$
UK/Mexico as a whole	t(916) = 9.308, $p < .001$, Cohen's $d = .63$
People in developing countries	t (916) = .367, $p = .714$
People in developed countries	t(915) = 3.163, $p < .001$, Cohen's $d = .21$

Nevertheless, when analysing the perception about the impact of CC in developing countries, results reflected that a majority of respondents in both countries perceive CC as a very or extremely serious threat (see *Appendix C.6).* The difference between countries is significant ($z = 2.583$, $p < .01$) - UK (61.4%) and Mexico (70.1%). Similar results for the UK were found in the ResilRisk project (Steentjes et al., 2020), where 67% of British respondents described CC in developing countries as serious or extremely serious. Even though both countries perceive CC to be a higher risk for developing countries, the Mexico sample perceives it as a more serious threat.

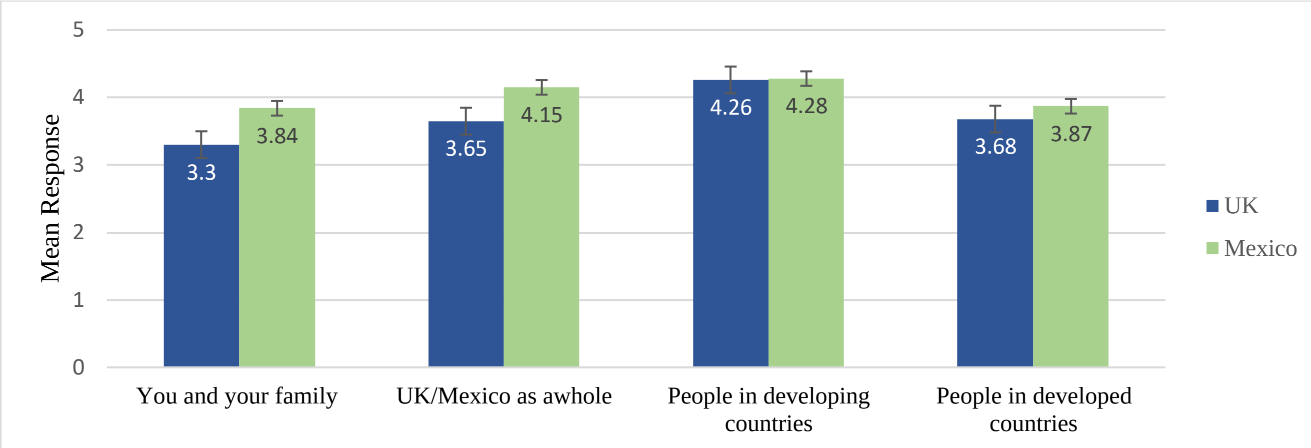

Figure 7.3. Mean response for seriousness of CC
You and your family, Mexico (M = 3.84, SD = 0.75) UK (M = 3.30, SD=0.95). UK/Mexico as a whole, Mexico (M = 4.15, SD = .71) UK (M = 3.65, SD = .90). People in developing countries, Mexico (M = 4.28, SD = .75) UK (M = 4.26, SD=0.86). People in developed countries, Mexico (M = 3.87, SD = .84) UK (M = 3.68, SD = 0.88). Responses were made on a 5-point scale 1=Not at all serious 2= Not very serious 3=Fairly serious 4= Very serious 5= Extremely serious. Error bars represent ±1 standard deviation.

Following the topic of CC seriousness, respondents were asked to rate how much CC is going to harm them personally (Q.12). Results for this question confirm the results obtained previously: 65% of Mexican respondents believe CC is going to harm them a great deal where the UK only 19.8% shared this level of concern. Instead, most of the British respondents believe CC will harm them a moderate amount (48.9%); t(915)= 16.862, $p < .001$, Cohen's $d = 1.14$.

The next question was focused on responsibility (Q.13), asking respondents about their view on who should be responsible for taking action against CC. In general, the responses for both countries followed a similar pattern. Respondents in the UK and Mexico agreed it is the national government that is mainly responsible to address this issue (UK 75.4%, Mexico 83.7%) followed by industry (UK 61.1%, Mexico 80.8%) and then by society or the international community. Environmental groups were seen as least responsible for acting against CC.

Although there is a similar pattern in perception about responsibility between countries as observed in *Figure 7.4*, numbers in Mexico appear to be higher than in the UK. A z-test reflects a significant difference between countries in regards of the role of all the institutions; Industry ($z = 6.588$, $p < .01$), National Government ($z = 3.095$), $p < 0.01$), Society ($z = 9.091$, $p < 0.01$), Local Government ($z = 6.472$, $p < .01$), Individuals and their Families ($z = 7.337$, $p < 0.01$), Environmental Groups ($z = 6.730$, $p < 0.01$), and the International Community ($z = 3.623$, $p < 0.01$).

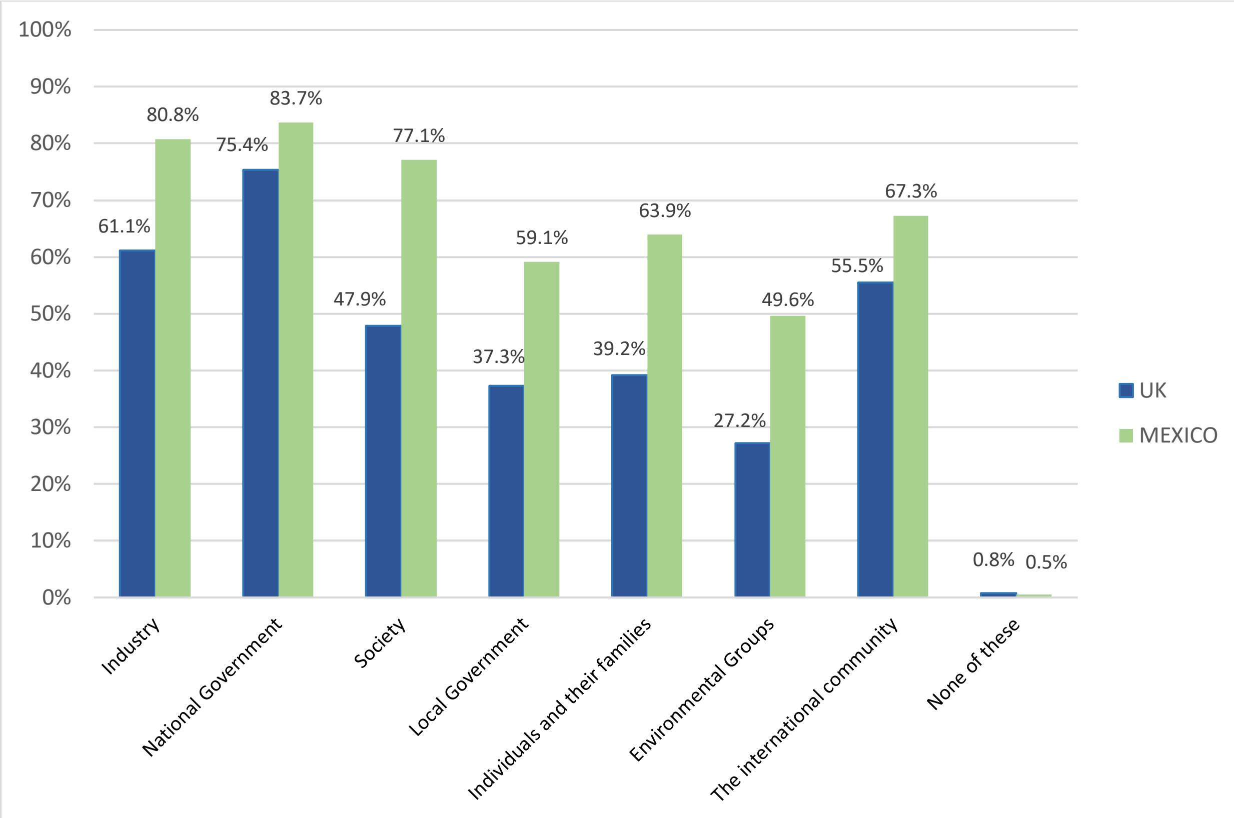

Figure 7.4. Survey results for responsibility for taking actions against CC (Percentages) (Q.13)

7.3.3. Overpopulation

Overpopulation is one of the most important topics when talking about CC, some would even describe it as the "root of the problem" (Marx, 2020). Nevertheless, we need to take into consideration that the impact on CC from developed nations is significantly larger than developing countries (Alberro, 2020). According to a report conducted by the Stockholm Environment Institute (SEI) and Oxfam, the richest 10% of the population were responsible for 49% of carbon emissions in 2015, whereas the poorest 50% were responsible for only 7% (Kartha et al., 2020). This supports the statements that higher economic growth is generally associated to higher emissions (Ravallion et al., 2000). This 'inequality in emissions' requires to be acknowledge when referring to overpopulation as one of the main causes of CC.

Several articles, affirm that the single most effective measure an individual in the developed world could take to cut their carbon emissions over the long term could be having smaller families "one fewer child per family" (Carrington, 2017). This statement was presented to respondents to understand their perception about the impact of overpopulation on CC and to compare this point of view between countries. As detailed in the previous section, respondents were asked to rate this perception on a 5-point scale (1-strongly disagree, 5- strongly agree).

Results from the surveys suggest that there is a significant difference between countries, t(917) = 6.839, $p < .001$, Cohen's d = .46; in general we can state that a majority of Mexican respondents tend to agree with limiting the number of children per family as a measure to tackle CC (M = 3.78, SD = 1.33) whereas in the UK respondents seem to be more neutral about this topic (M = 3.17, SD = 1.32). 62.8% respondents from Mexico strongly or tend to agree with the statement, where in the UK only 46% feel this way. However, 23.5% of British participant neither agree nor disagree (*see Figure 7.5*).

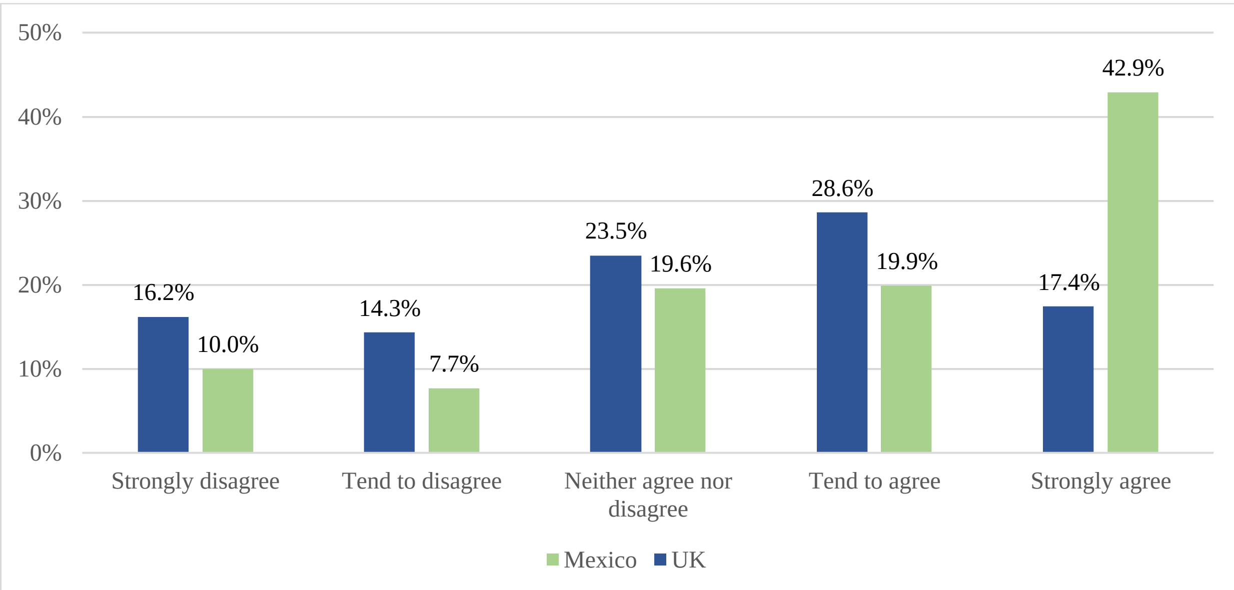

Figure 7.5. Perception about overpopulation (percentages).
(Q.15) A study published in 2017 by the Universities of Lund and British Columbia, suggested that the single most effective measure an individual in the developed world could take to cut their carbon emissions over the long term, could be having smaller families (one fewer child per family). What do you think about limiting the number of children per family as a measure to tackle CC?

7.3.4. Climate change Knowledge

7.3.4.1. Knowledge about Energy Sources

In this section the aim was to analyse respondents' knowledge about zero-carbon energy sources and their views around the current impact of fuels on the environment. Generally, as we can observe in *Figure 7.6 and Figure 7.7*, both countries follow the same pattern of knowledge about fuels, however there are several differences between them[35]. A table summarising the chi-square analysis for each fuel is presented in Appendix C.6j.

[35] Due to the use of crosstabulations and chi-square tests, country differences such as for age, education and political orientation were not taken into consideration in this analysis.

It is evident that in both countries the majority of people understand the climate impact of fossil fuels (coal, diesel, gasoline, LP and natural gas), although respondents in the UK tends to be less likely to say they contribute to climate change compared to Mexican respondents. This is reversed for LP gas, where Mexican respondents were more likely to say it contributes to climate change compared to the UK.

For biomass and biofuels, there seems to be less knowledge about their impact on the environment. A high percentage, especially in the UK, stated they *don't know* about the impact of these two fuels (UK: Biomass 34.7%, Biofuels 31.4%) (Mexico: Biomass 19.4%, Biofuels 14.4%). Also important to note is for Mexican respondents, 39.3% claimed to have never heard of biomass even though this type of energy represents 8% of the Mexican electricity supply (Secretaría de Agricultura y Desarrollo Rural, 2019).

These previous fuels are not the only ones where respondents displayed lack of knowledge or unfamiliarity. Interestingly the data suggests that for both samples, Mexico and the UK, the fuel that people have more doubts about is hydrogen, which is extremely important for this research as ammonia fuel is based mainly on *hydroge*n which implies that if the technology is presented to laypeople, a majority might not consider hydrogen as carbon-free. A study about hydrogen conducted in Wales in 2008 (Cherryman et al., 2008) found that when presenting the concept of hydrogen as a fuel to the general public, there is some confusion. Most people understood that water was H_2O (hydrogen and oxygen) however some respondents associated it with something explosive, mentioning the hydrogen bomb. Perhaps because of the concern about hydrogen safety, there is a confusion about its impact on the environment. This uncertainty also seems reflected in the following survey question (Q.17) where the support for each fuel was measured.

With regards to *nuclear energy*, a majority for both countries believes it contributes to CC (UK: 43.1%, Mexico 58.4%), but this is higher in Mexico than in the UK. A relatively high percentage of respondents answered that they don't know if it contributes to CC, especially in the UK (UK 22.7%, Mexico14.6%). This answer is in line with previous research where 39% of British respondents strongly agree or tend to agree that generating electricity from nuclear power causes CC (Poortinga et al., 2005).

Regarding renewable energies (wind, solar and tidal), the responses seem to be similar across both country samples, with a majority of respondents believing that none of these energy sources contribute to CC. However, for tidal energy, UK respondents were more likely to say it doesn't contribute to climate change (77.2%) compared to Mexico (52.1%) and less likely to say they don't know (8.7% vs 18.7% in Mexico). For hydroelectric, Mexican respondents were more likely to say it contributes to climate change.

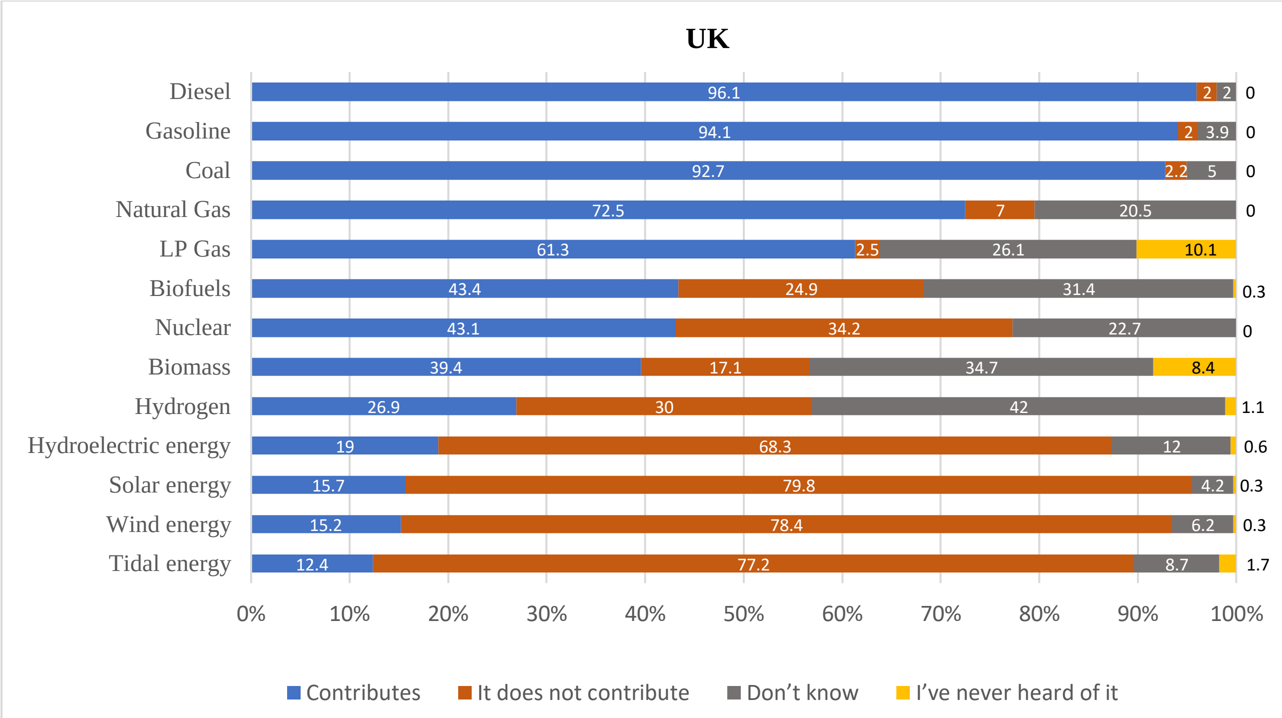

Figure 7.6. Percentage of responses for knowledge about energy sources in the **UK** (Q.16)
"Do you believe the following fuels/energy sources contribute to CC?" Ordered according to perceived contribution.

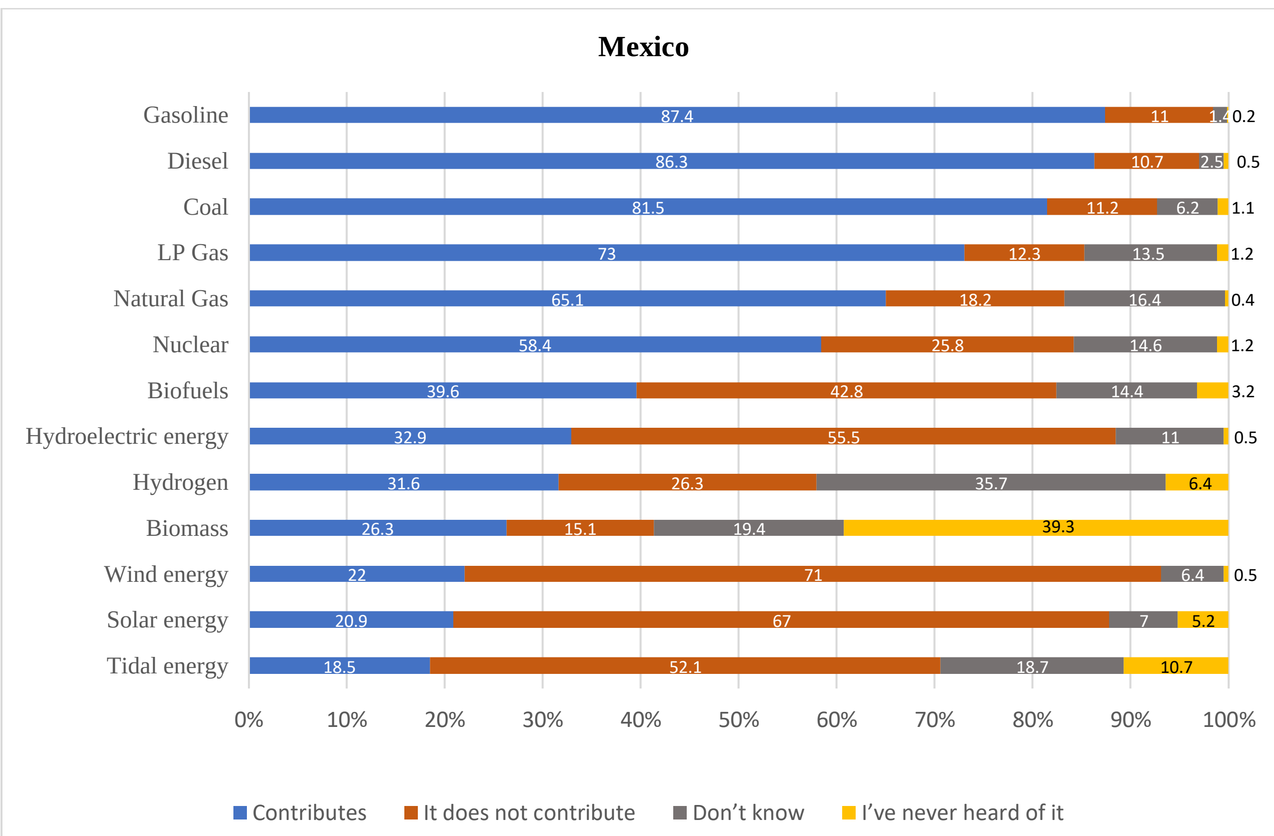

Figure 7.7. Percentage of responses for knowledge about energy sources in **Mexico** (Q.16)
"Do you believe the following fuels/energy sources contribute to CC?" Ordered according to perceived contribution.

It is important to highlight that low levels of knowledge about energy sources might have been due to lack of familiarity with the energy type and not specifically about the technology. Future research could include a short description of each energy source to address this limitation.

After examining respondents' knowledge about the impact of fuels on the environment the survey intended to analyse the support or opposition of the use of these same fuels (see *Figure. 7.8*).

We can observe that both countries tend to oppose the use of most of the carbon-based fuels (coal, diesel and gasoline) however, in the UK a high number of respondents still have a neutral attitude of these fuels answering *neither oppose nor support* (coal 20.4%, diesel 27.7%, gasoline 33.6%). Nonetheless the case of LP gas is interesting because a majority in the UK maintains a neutral perspective (45.8%) and in Mexico perceptions are more divided (oppose 28.6%, neutral 22.6%, support 29%). For natural gas, a majority of British respondents maintained a neutral perspective (44.6%) whereas in Mexico the decision was divided with a majority supporting its use (33.5%) (neutral 21.9% and oppose 21.4%). Significance difference testing (Appendix C.6g) shows no differences across countries when it comes to average support/opposition to these fuels, except for natural gas, where Mexican respondents are more supportive than UK respondents.

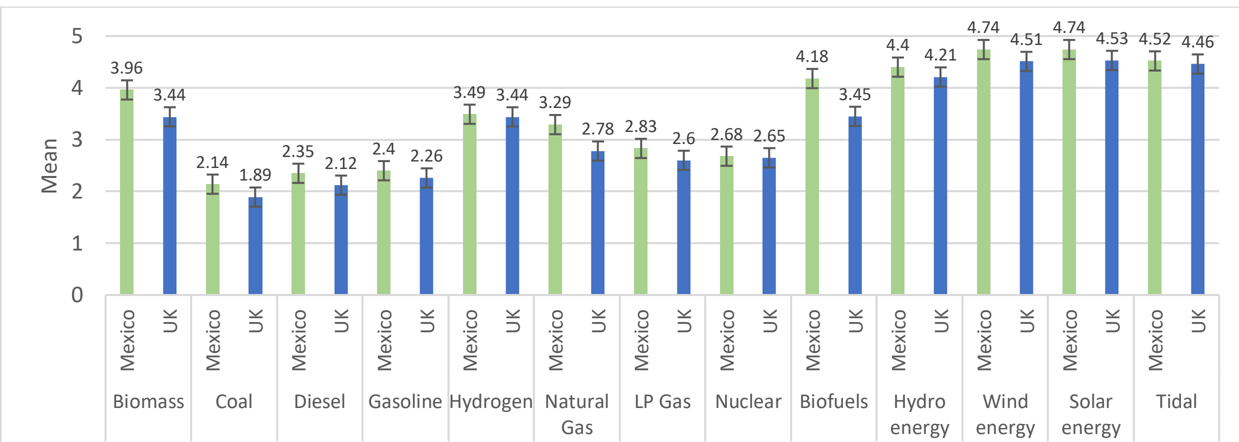

Figure 7.8. Mean responses for support of fuels (Q.17).
Responses were made on a 5-point scale 1=Strongly oppose 2= Oppose 3=Neither support nor oppose 4= Support 5= Strongly support (99=I've never heard of it [36]). Error bars represent ±1 standard deviation.

For biomass and biofuels there was a significant difference between countries; Biomass t(565) = 6.651, $p < .001$[37] Biofuels t(860) = 10.352, p = < .001; whereby on average Mexican respondents were more supportive of both biomass and biofuels. However, it should be noted that a large proportion of Mexican

[36] "I've never heard of it" was excluded from the t-test to obtain accurate mean responses.
[37] Bonferroni correction to $p < 0.003$

respondents indicated that they have never heard of biomass (51.9%), this was not the case for biofuels only 7.3% responded to have never heard of it.

For hydrogen no significant differences were found. A large number of respondents from the UK and Mexico indicated to *strongly support* or *support* the use of this fuel (Mexico 41%, UK 40.7%). A higher number in the Mexican sample *strongly oppose* or *oppose* its use (Mexico 16.6%, UK 7.5%). Whereas, a majority of British respondents remained neutral (UK 46.9% and Mexico 23.2%) and a high number in Mexico has never heard of it (Mexico 19.3%, UK 4.8%) (*see Appendix C.6h*).

For nuclear power, the analysis reveals similar results with no significant differences between countries. A majority of respondents for both countries *oppose* or *strongly oppose* to the use of this energy source (UK 45.1%, Mexico 45.4%). Nevertheless, 28.7% of British respondents *neither support nor oppose*. Results from the UK are slightly different than previous surveys (Poortinga et al., 2005) where the opinion from respondents was similarly divided between *oppose* and *neither support nor oppose* (*oppose* 37%, *neither support nor oppose* 32%). However, we also need to consider that our sample is more left leaning, which might explain why a majority of respondents oppose the use of this energy source.

For renewables energies the pattern was also similar - a majority indicating that they support or strongly support the use of these technologies in both countries (*Hydroelectric*: Mex 84.1%, UK 81.4%; *Wind* Mex: 92.3% UK: 94.1%; *Solar* Mex: 86.8% UK 93.8%; *Tidal* Mex 68.5% UK 88.1%). However there was a significant difference for two of them: *wind energy* $t(904) = 5.257$, $p < 0.001$ and *solar energy* $t(871) = 4.994$, $p < 0.001$, whereby Mexico was slightly more supportive than the UK on average.

7.3.4.2. Knowledge about climate change

In the focus groups, limited knowledge about CC was noted for Mexican respondents. For this reason, and combined with the fact that there is limited information about this topic in Mexico, we measured CC knowledge in the surveys. CC knowledge was measured across three categories (physical characteristics, causal knowledge and consequences knowledge), each with two questions (see section *7.2.3.5* for details)

In general, respondents in both countries have a good baseline knowledge about CC with a majority answering most of the questions correctly.

For *physical characteristics* (*see Figure 7.9*) most of respondents are aware of the impact of oil on the environment with the majority (UK 84.9%, Mexico 82.8%) indicating correctly that burning oil produces CO_2. There were no differences between countries; $\chi(2) = 1.453$, $p = .484$. However, there also appears a relatively high percentage of respondents in both countries who state they don't know about its impact (UK 12.9%, Mexico 13.7%). Regarding nuclear energy, similar results to previous questions about this energy source were found; people are confused about the impact of nuclear energy on the environment, although there is a significant difference between countries; $\chi(2) = 10.069$, $p = .007$, both have a divided opinion, for the UK a majority (37.5%) indicates nuclear power plants *do not* emit CO_2 during operation, 32.9% *don't know* and 29.7% think they do. In the case of Mexico, the opinion is the opposite, a majority (38%) believe nuclear power plants emit CO_2 during operation, 33.6% *don't know* and the lowest percentage (28.4%) got the correct answer saying nuclear plants do not emit CO_2.

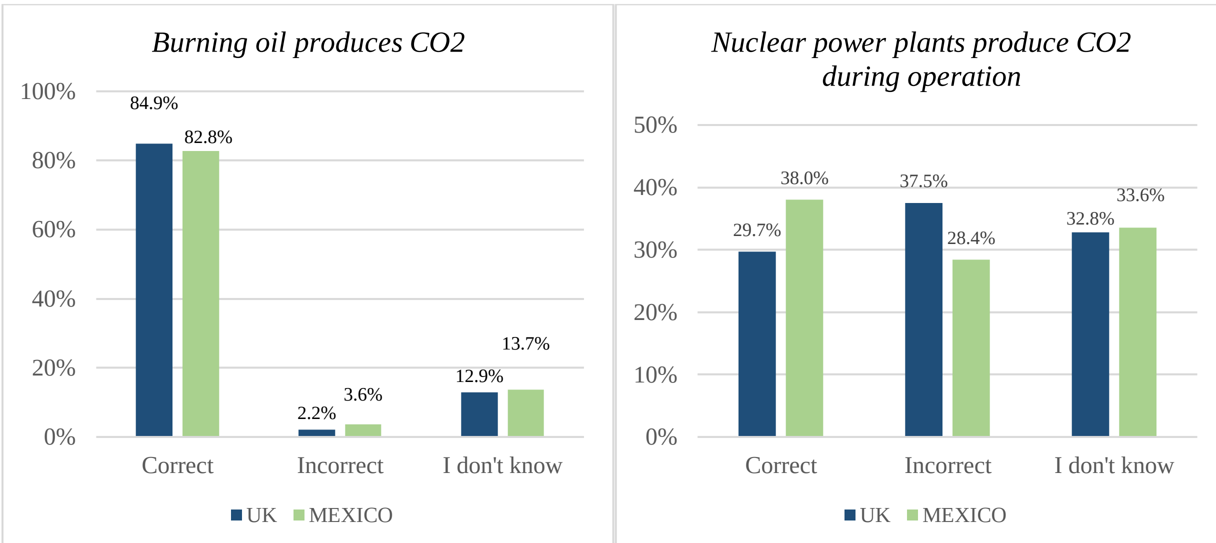

Figure 7.9. Percentage of responses for first two statements of Q.18 (physical characteristics).

For *causes knowledge*, (see *Figure 7.10*) both countries followed the same patterns. For the first statement "*The global* CO_2 *concentration in the atmosphere has increased during the past 250 years*" a majority got the answer right answering that this statement is correct (UK 91.6% and Mexico 87%). The Mexico sample, however, still has a noticeable percentage of *don't know* answers compared to the UK (Mexico 11.7%, UK 6.4%); $\chi(2) = 7.548$, $p = .023$[38]. For the second statement in this category "*The last century's global increase in temperature was the largest during the past 1,000*" the opinion was divided between respondents in both countries $\chi(2) = .308$, $p = 0.857$. A larger number of respondents answered correctly (UK 81%, Mexico 80.3%), but in this occasion both countries got a relatively high percentage of *don't know* answers (UK 17.1%, Mexico 18.1%).

[38] This should be considered non-significant when applying a Bonferroni correction to account for multiple comparisons.

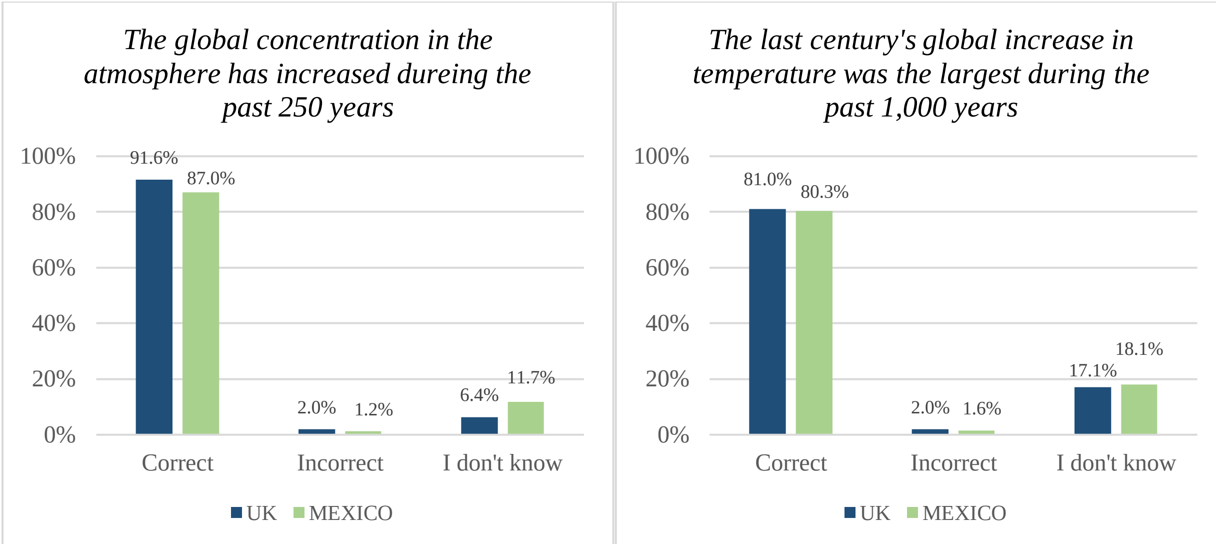

Figure 7.10. Percentage of responses for last two statements of Q.18 (causes knowledge).

In the last block of statements about *consequences knowledge*, the first statement seems to be very straight forward for respondents "*For the next decades, the majority of climate scientists expect……an increase in extreme events, such as droughts, floods and storms*" with a majority indicating that this statement was correct (UK 96.1%, Mexico 95.7%) and with low percentages of don't know answers (UK 3.4%, Mexico 2.5%); $\chi(2) = 3.071$, $p = .215$. Nevertheless, for the second statement "*For the next decades, the majority of climate scientists expect……the climate to change evenly all over the world*" there was a significant difference between countries, $\chi(2) = 61.533$, $p < .001$ (see Figure 7.11). A majority in both countries got the answer right with a higher percentage indicating that this statement was incorrect (UK 68.9%, 44.6%), but still a large number of Mexican respondents believe climate is going to change evenly all over the world (41.9%) and in both countries there was a high percentage of respondents who say they 'don't know' (UK 12.9%, Mexico 13.5%).

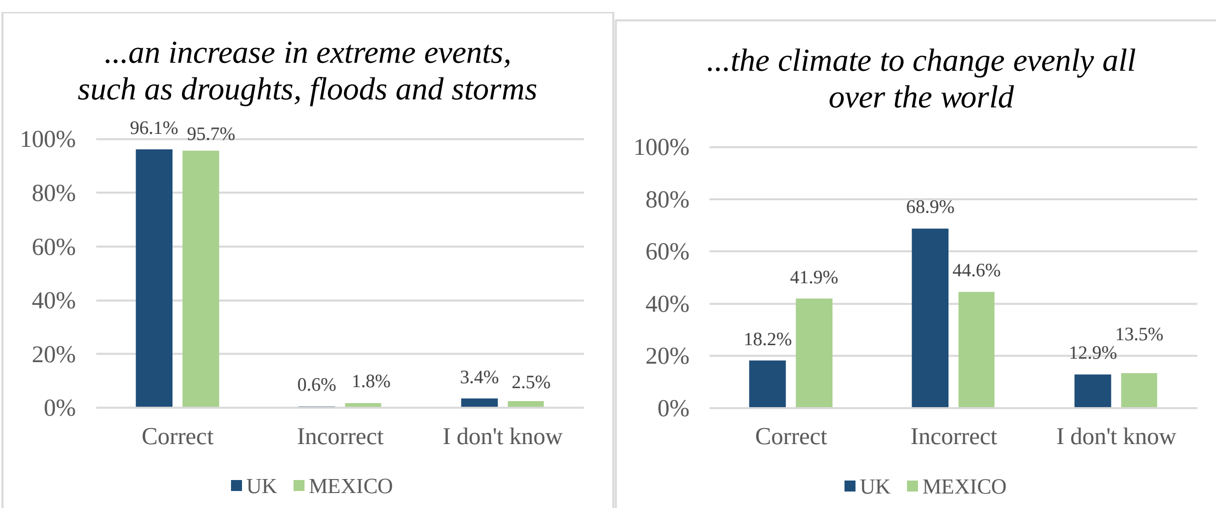

Figure 7.11. Percentage of responses for first two statements of Q.19 (consequences knowledge).
For the next decades, the majority of climate scientists expect…

7.3.5. Green Ammonia

This section will present the results for questions concerning public perceptions of ammonia. The first question about this topic was displayed at the beginning of the survey, straight after demographics, and only asked to list the first thoughts or images that come to mind when hearing the term 'ammonia' (Q.7). No previous information about the chemical was given to respondents. This question intended to gain an understanding of people's initial images and affective responses to ammonia as a chemical.

Examining both samples together first, most of the respondents (18.4%) answered with a broad concept using words like "chemical" or "chemical compound/substance" but with no negative or positive connotation, (*see Appendix C.7a*). However, similar to the results obtained from the FGs, 17.4% from the whole sample had a slightly more negative beliefs about ammonia referring to it as "poison" "toxic" "corrosive" or acid". Only 8.6% used the actual words "dangerous" "not safe" or "bad for humans". An interesting observation was that the association with "killing" "bomb" and "death" came up again, although in a low number of respondents (7). is suggests that ammonia is associated with some risk perceptions especially around human health and evokes negative images in people's minds. However, there were also more neutral images with the word ammonia because it was associated to familiar cleaning products:

The third most mentioned concept in general, was about its use as a cleaning product; 15.4% knew that ammonia was in cleaning or disinfecting products whereas 2.5% mentioned other products such as hair dyes, tanning products and painting. Regarding the smell, 14.1% mentioned this characteristic as a first thought and 7.1% associated it with urine or manure.

However, if we look at the data from each country separately and rank them by frequency of mentioning a topic, several differences become evident. Results show that for the UK sample the most popular answer was associated with smell with 23.2% of respondents commenting about it as a first thought when hearing the word ammonia. This was followed by mentions of urine/manure (15.1%) and cleaning products (13.7%).

In the case of the Mexican sample, mentions about odour only represented 7.1% of respondents, on the contrary to the UK the most mentioned answers in Mexico were "poison" "toxic" or "acid" (25.2%) followed by just mentioning "chemical" (22.6%) and in third place, cleaning products (16.5%).

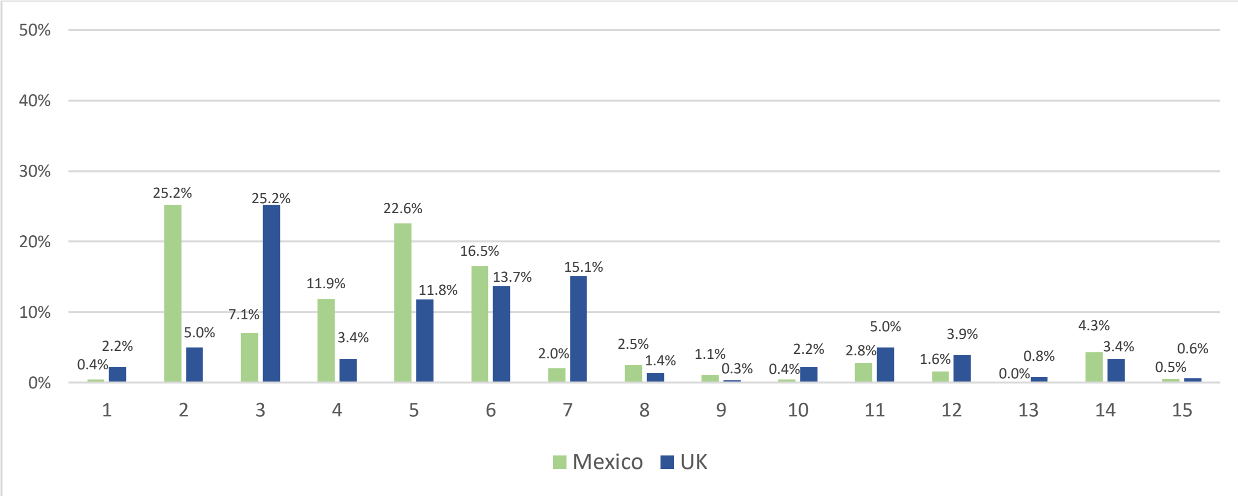

Figure 7.12 Percentages for most common answers by country of <u>first associations of ammonia</u> (Q.7).
(1) Nothing/Don't know (2) Poison/toxic (3) Smell (4) Safety (5) Chemical (6) Cleaning products (7) Urine/manure (8) Pollutant (9) Death/killing (10) Fuel (11) Fertilizer/refrigerant (12) Other products (13) Negative (14) Substance (15) Confusion with other chemicals.

At a later stage in the survey, respondents were given an infographic and text (*see previous methodology section 7.2.3.5*) explaining what ammonia is, how it is currently being produced and then the concept of green ammonia was introduced in simple terms.

Following this explanation, a second open-ended question was asked "*Please tell us what thoughts or images came to mind when reading this information about green ammonia?".* Results from this question show the respondents; reactions and perceptions of ammonia when framed in terms of a technological solution to climate change. As we can observe in figure 7.13, in both countries the majority of respondents (Mexico 30.2%, UK 39.5%) answered with positive comments about this technology using words such as "promising" "beneficial" "amazing" "great idea" "excellent option". As such, benefit perceptions were clearly evident. Following these answers, the most common response for Mexico were related to a novel concept (18.7%), answering "I've never heard of it" "completely new" "surprising", whereas for the UK the second most mentioned answer was also a novel concept (8.4%) and "don't know" "nothing" or not answering the question (8.4%).

Comments relating "poison" or "toxic" with ammonia got a very low percentage in this question (Mexico 1.8%, UK 0.6%) and instead a high percentage mentioned positive comments relating ammonia with the environment (Mexico 9.4%, UK 8.1%) i.e., "good option for the environment" "good green fuel" "less pollution". This is perhaps not surprising given that the text provided green ammonia as a possible solution towards CC and highlighted this particular benefit of the technology. Nevertheless, sceptical answers about the technology got a relatively high response as well in both countries (Mexico 7.1% and UK 8.1%) stating that they don't believe in the graphic presented "I don't believe it" "Not sure it can work" "weird" "It will end up not working".

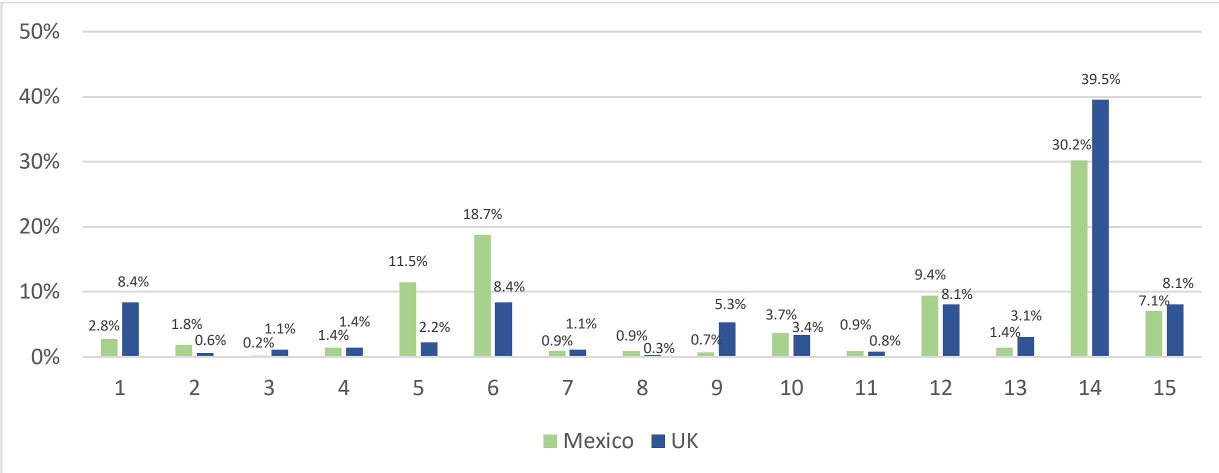

Figure 7.13 Percentages for most common answers by country of <u>perception of green ammonia</u> (Q.7).
(1) Nothing/Don't know (2) Poison/toxic (3) Smell (4) Safety (5) Solution/alternative (6) Novel concept (7) Cost (8) Pollutant (9) Complex/confusing (10) Need more information (11) Water (12) Positive for the environment (13) Negative (14) Generic positive (15) Sceptical.

After presenting the infographic, respondents were asked to rate on a 7-point scale (from 1-Extremely negative to 7- Extremely positive) how they feel about green ammonia to gauge initial affective responses to the technology. Responses from both countries were similar (UK M = 5.63, SD = 1.08; Mexico M = 5.77 SD = 1.10) with a majority of the answers being positive. A t-test revealed there was no significant difference between the samples, t(912)= 1.891, *p* = .059.

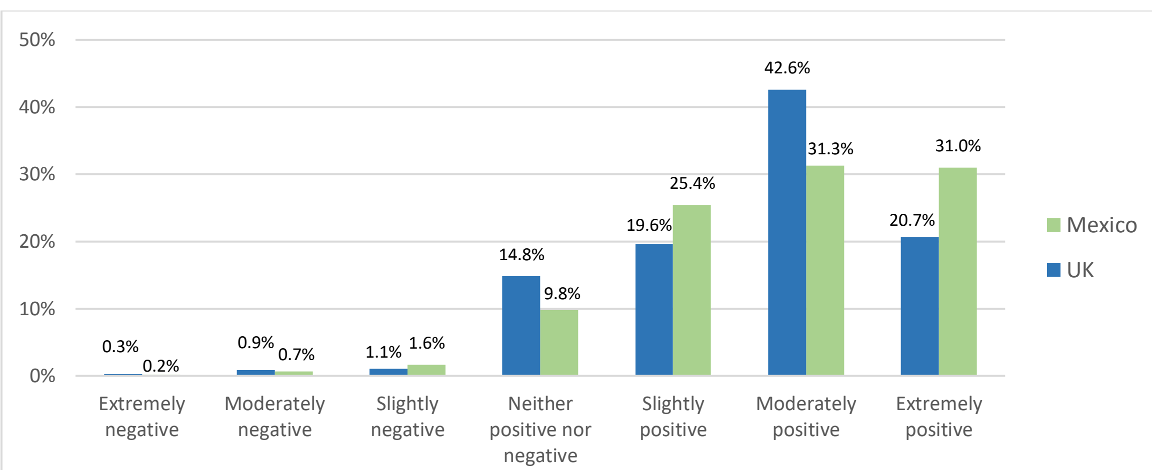

Figure 7.14 Percent of responses for Q.21 about opinion of green ammonia technology.
Responses were coded as follows: 1-Extremely negative (UK 0.3% Mexico 0.2%) 2- Moderately negative (UK 0.9% Mexico 0.7%), 3-Slightly negative (UK 1.1%, Mexico 1.6%), 4- neither positive nor negative (UK 14.8%, Mexico 9.8%), 5-Slightly positive (UK 19.6%, Mexico 25.4%), 6-Moderately positive (UK 42.6%, Mexico 31.3%), 7-Extremely positive (UK 20.7% Mexico 31%).

7.3.5.1. Risk and Benefits

Once the information about green ammonia was given to respondents and their first perception of the technology was recorded, a list of benefits and risks was presented in order for them to rate how positive or worried they feel about these.

First, four benefits were presented where they were asked to rate on a 5-point scale from 1- *Not at all positive* to 5- *Extremely positive*. Results confirm a similar patter between countries when rating the benefits; the graph below shows in order of preference each of the benefits (*see Figure 7.15*)

The benefit respondents feel most positive about in both countries (*see Figure 7.16*) is the zero-carbon property of this fuel (UK M = 4.25, SD = .82, Mexico M= 4.35, SD = .79), followed by using animal waste to produce energy (UK: M = 4.12, SD= .82, Mexico M = 4.30, SD = .76) and the established infrastructure (UK: M = 4.05, SD = .92, Mexico M = 4.13 SD = .84).

Nonetheless, for the second benefit mentioned (animal waste) a significant difference was found between countries, $t(881) = 3.387$, $p = .001$, Cohen's $d = .23$, where the Mexican sample felt more positive about this advantage. Additionally, for both countries the least favourite benefit was the penetrating smell to detect a gas leak (UK: M = 3.67, SD = .84, Mexico M = 3.98, SD = .85), with British respondents being less positive than Mexican respondents, $t(875) = 5.13$, $p = 0.000$, Cohen's $d = 0.36$.

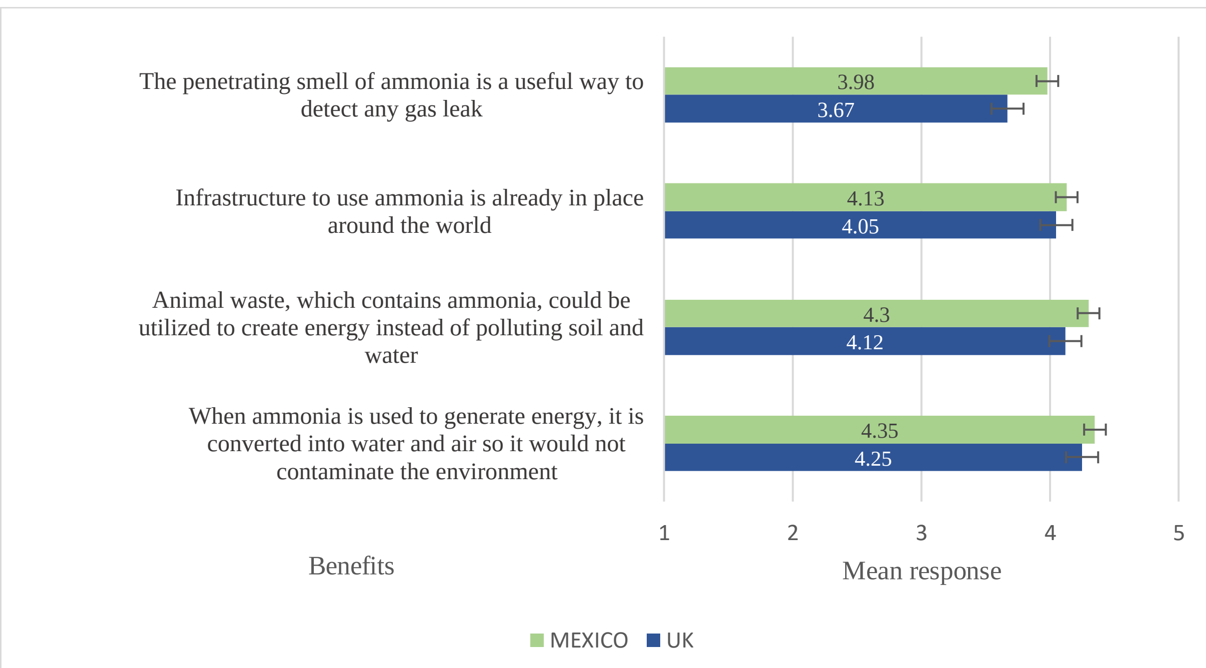

Figure 7.15. Mean response for benefits about green ammonia (Q.22).

How positive do you feel about the following benefits…Responses were coded as follows: 1- Not at all positive 2- Not very positive 3- Somewhat positive 4- very positive 5- extremely positive.

Secondly, for risks, respondents were presented with five different risks and they were asked to rate them on a 5-point scale from *1- Not at all worried* to *5- Extremely worried*. On the contrary to benefits, perception of risks was different between countries, an independent-samples t-test revealed significant differences on every risk statement.

Table 7.8 To what extent are you worried about the following risks…

Risk	UK		Mexico		t-test, two tailed[39]
	Mean	SD	Mean	SD	
Ammonia is a toxic gas that when inhaled in large concentrations can cause burns in eyes and mouth	3.32	0.89	3.64	0.88	t(887) = 5.24, *p* = 0.000, Cohen's *d* = .36
As a fuel, if ammonia is not burned properly, NOx particles (a type of greenhouse gas) can be released, contributing to climate change	3.55	0.79	3.82	0.81	t(875) = 4.84, *p* = 0.000, Cohen's *d* = .34
Ammonia technology to store and generate energy would need large investments to commercialize, this might imply higher prices in electricity	2.98	0.89	3.63	0.85	t(743.45) = 4.87, *p* = 0.000, Cohen's *d* = .75
Ammonia has a very unpleasant smell	2.79	1.03	3.14	1.10	t(888) = 4.69, *p* = 0.000, Cohen's *d* = .32
Ammonia technology is water intensive so it would need to be developed in areas with easy access to water	3.04	0.99	3.86	0.93	t(869) = 12.20, *p* = 0.000, Cohen's *d* = 0.85

As we can observe from Table 7.8, for UK respondents the main worry was about possible NOx emissions if ammonia is not burned properly (M = 3.55, SD = .79), whereas in Mexico their main concern was about the intensive water use of the technology (M = 3.86, SD = .93). The latter result goes in line with prior information obtained in the previous research phase where one of the most common questions within FGs in Mexico City and Cancun was focused on the water needed to develop this technology.

The second highest worry in the UK was the toxicity of the gas when inhaled (M = 3.32, SD = .89), while Mexican respondents opted for NOx emissions (M = 3.82, SD = .81). These were followed by water intensity (M = 3.04, SD = .99) for the UK and toxicity of the gas for Mexico (M = 3.64, SD = .88). Interestingly, the possible increase of electricity prices seems not to be a main worry for neither of the countries (UK M = 2.98, SD = .89) (Mexico M = 3.63, SD = .85), nevertheless as we can observe in *Figure 7.16* this worry is significantly higher in Mexico than in the UK, t(743.45) = 4.87, $p < .001$.

[39] Bonferroni correction to p=<0.01

Even though smell came at the bottom of the benefits as the least positive characteristics of the technology, for concerns the unpleasant smell came as the least of the worries for both, Mexico (M = 3.14 SD = 1.10) and the UK (M = 2.79, SD = 1.03).

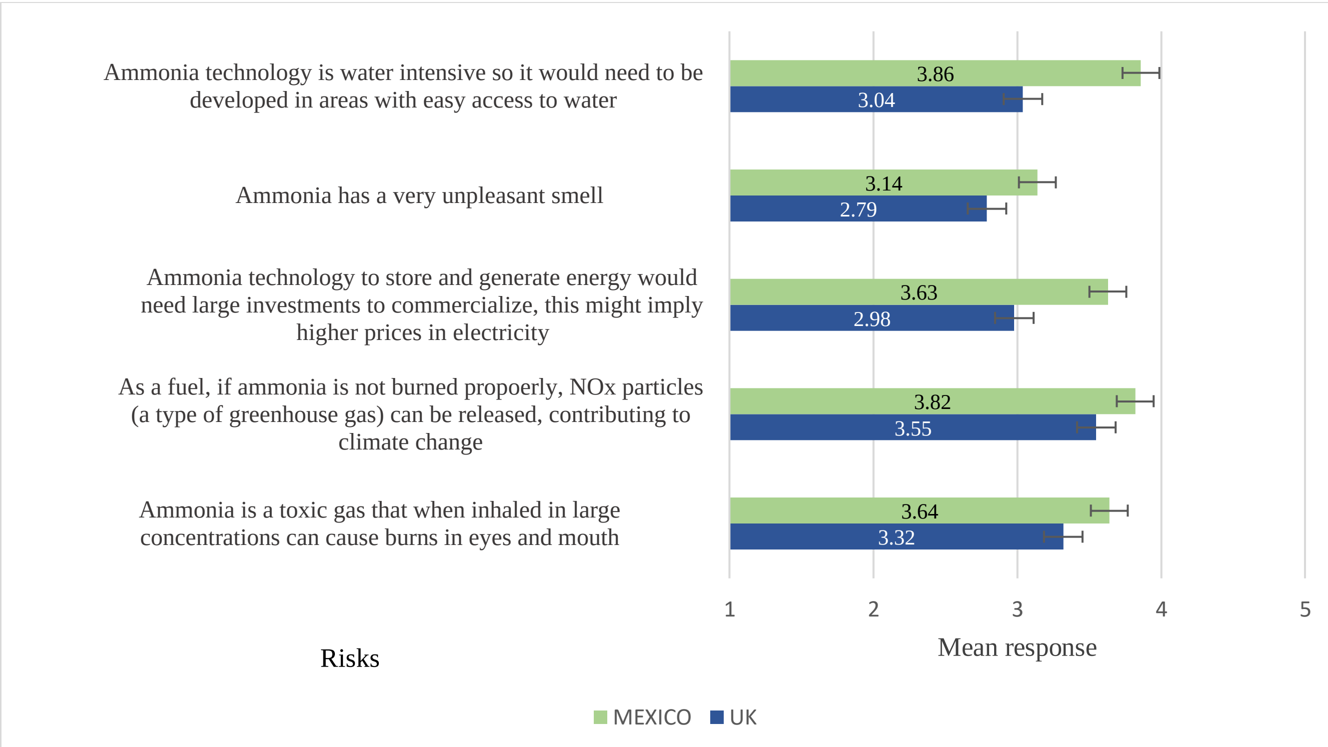

Figure 7.16. Mean response for risks about green ammonia (Q.23).
To what extent do you feel worried about the following risks… Responses were coded as follows: 1- Not at all worried 2- Not very worried 3- Somewhat worried 4- very worried 5- extremely worried.

Following the list of risks *(Q.24),* respondents were asked to rate on a 5-point scale *how acceptable or unacceptable were in general the risks of green ammonia* (1-Very unacceptable to 5-Very acceptable). Results were similar to previous findings with a significant difference between countries, t(904)= -3.662, $p < 0.001$ Cohen's d = -0.25, showing that Mexican respondents perceive the risks slightly less acceptable than British respondents (UK: M = 3.59, SD = .73, Mexico: M = 3.40, SD = .74).

Consequently, people were asked if there are more risks or benefits in this technology. Both samples agreed, as exhibit in *Figure 7.17*, that the benefits outweigh the risks (UK 45.3%, Mexico 47.8%) t(904) = .164, p = .870, nevertheless there is still a considerable percentage in both countries that believes the contrary (UK 15.8%, Mexico 17.4%).

Interestingly, regarding benefits of a new technology research suggests that despite a risk factor, people tend to be more concern about the extent of the benefit (development and application) than on the associated risks. In other words, how big is the benefit (for people or environment, not industry) compared to the risk. Public acceptance will be driven by perceived benefits as long as the risk is not so large to be intolerable.

(Frewer, 1999) Results from our survey are in line with these findings where respondents consider the benefits to be greater than the risks.

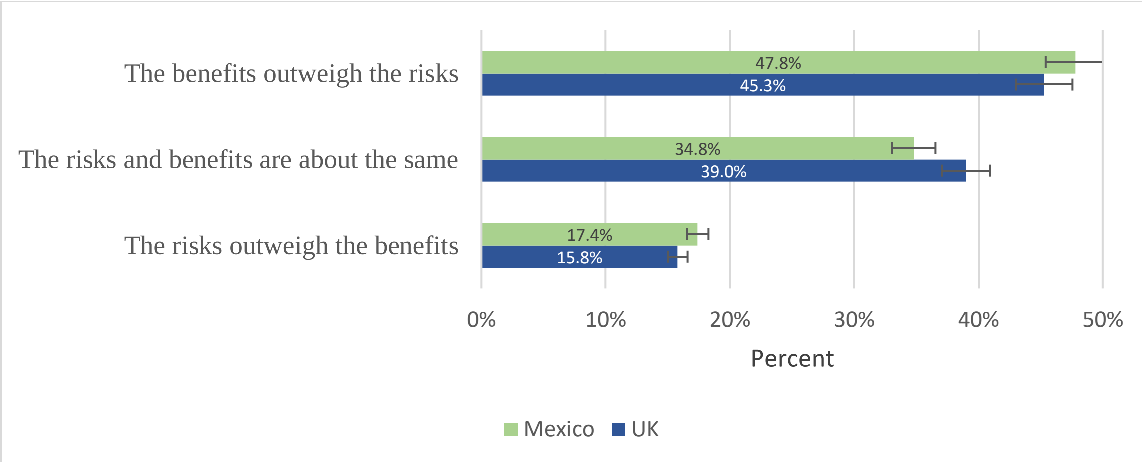

Figure 7.17. Percentage for response of Q.25.
Do you think there are more risks or benefits for green ammonia? 1- The risks outweigh the benefits 2- The risks and benefits are about the same 3- The benefits outweigh the risks

In general terms when comparing both countries in this section of risks and benefits, we could observe that Mexico sample feels slightly more positive about the benefits than the UK sample (UK M = 4.02, SD = .85) (Mexico: M = 4.19, SD = .81). However, when we look at the risks, Mexico is also more worried about the risks than the UK (UK: M = 3.13 SD = .91, Mexico: M = 3.61, SD = .91), indicating more extreme perceptions in both of the questions. These results were confirmed when asked about how acceptable or unacceptable the risks are, where Mexican respondents again tended to be more concerned about the risks than the UK. A possible explanation for this might be that despite the positive perception Mexican respondents have about the technology, one of the biggest concerns according to results obtained from the FGs is about legislation and the lack of control from the government, which might explain why Mexican respondents are more worried than the UK about the risks of ammonia technologies.

7.3.6. Ammonia in the UK (or Mexico)

This last block of questions had the objective to understand how acceptable respondents thought it would be to implement this type of technology in their country and who would they trust to regulate it.
The first question in this section was "*Would you support or oppose the use and development of green ammonia technologies in your country as a way to reduce carbon emissions? (Q.27).*

Results indicate similar answers between countries without a significant difference, t(913)= -0.725, p = .468. The majority of respondents in the UK and Mexico strongly support (UK 28%, Mexico 26.2%) or somewhat support (UK 44.9%, Mexico 49.6%) the development of this technology in their country (UK M = 3.97, SD = .81) (Mexico M = 3.93, SD = .89)[40]. Negative results indicating a strong or somewhat opposition were very low only representing 3.1% for the UK and 7.4% for Mexico.

Consequently, respondents were asked *How feasible do you think the development of this kind of projects (e.g. ammonia technologies) might be in your country?* Results obtained for this question in both countries indicate a large number of respondents are unsure about the feasibility of this technology (UK 30.8%, Mexico 29.6 %). Nonetheless, UK respondents thought the development of ammonia technologies in their country was more feasible than Mexican respondents, t(913) = -10.679, $p < .001$, Cohen's $d = -0.73$.

As *Figure 7.18 shows*, most of the respondents in the UK perceive green ammonia to be definitely or probably feasible (64.1%) followed by 30.8% who are not sure and 5.1% considering is probably or definitely not feasible. However, in the case of Mexico, is very different as it looks like the perception is more divided. On one hand we have 36.9% considering that the technology is definitely or probably feasible and on the other hand, almost the same percentage (33.5%) believing is probably or definitely not feasible. Additionally, a high number of respondents indicated not being sure (29.6%).

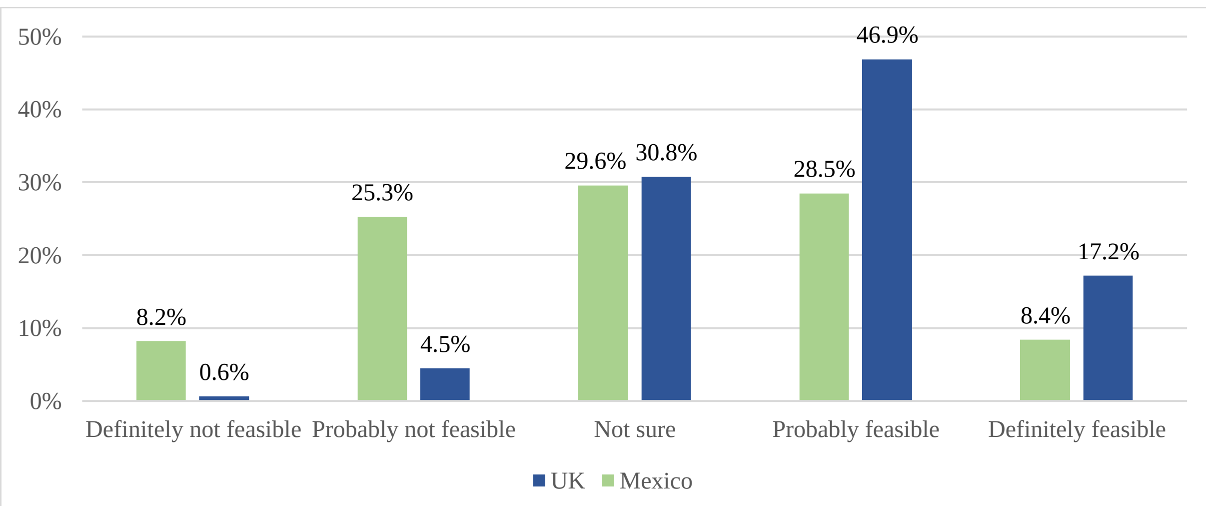

Figure 7.18. Percentage of the results obtained for Q.28
"How feasible do you think the development of this kind of projects (e.g. ammonia technologies) might be in the UK (Mexico)?"

A different perspective about the technology is also observed in Q.29 *If we use this technology in the UK/Mexico, who would you trust to regulate it?* Respondents were asked to choose between four options: *government*, *industry*, *both* or *none*. For British respondents the most trustworthy institution to regulate this

[40] Results were coded as follows: 1-Strongly oppose, 2-Somewhat oppose 3-Neither support nor oppose, 4-Somewhat support, 5-Strongly support

technology is a combination between government and industry (43.8%), which is a higher percentage than chosen by Mexican respondents (35.1%), $z = 2.734$, $p < .01$. For Mexican respondents the industry was their first, most trustworthy option with 44.6%. Only 4.8% of people in the UK showed trust in industry. Only 3% of Mexican respondents trust the government to carry out this job. Additionally, it is important to note that a large number of respondents in both countries replied that they don't trust in neither of these actors to regulate green ammonia (UK 21.8%, Mexico 17.3%).

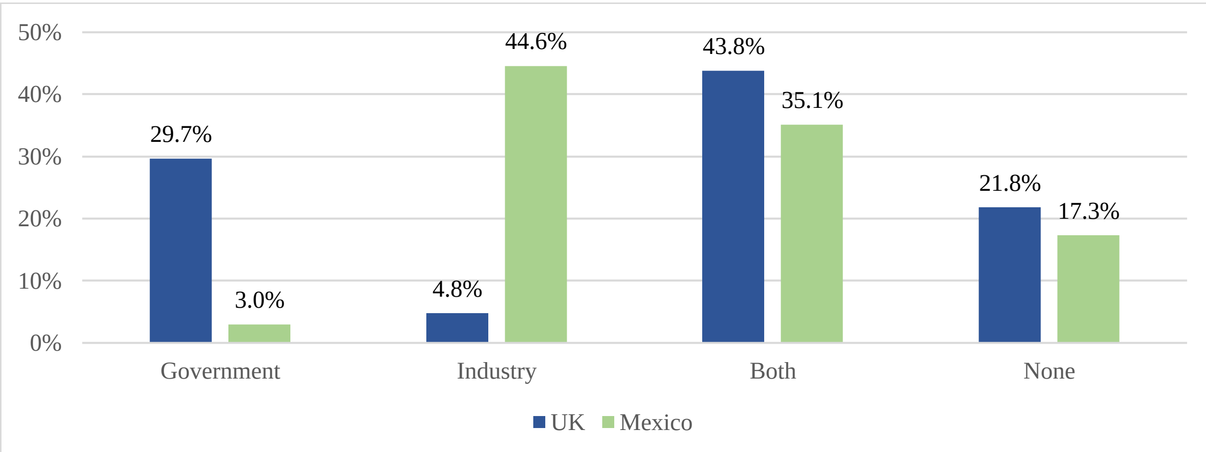

Figure 7.19. Percentage of responses for Q.29
"If we use this technology in the UK, who would you trust to regulate it?".

Considering the results obtained previously, further analysis was performed to understand the relationship between trust and support from green ammonia technologies. A regression established a significant relationship between these two variables. Indicating that trust in government predicts support for green ammonia technologies in both countries; Mexico, $F(3, 557) = 15.265$, $p < 0.001$, UK, $F(3, 350) = 5.509$, $p < .001$ (*see Table 7.9 below*). For the UK, trust in at least one of the institutions also predicts support for green ammonia technologies.

Table 7.9. Linear regression analysis of trust on support for green ammonia technologies [41]

	Mexico			UK		
Independent Variable	***B***	**SE**	**p**	***B***	**SE**	**p**
Trust (Government)	3.71	0.20	***	4.08	0.07	***
Industry	0.39	0.21	n.s.	0.04	0.20	n.s.
Both	0.28	0.21	n.s.	-0.02	0.10	n.s.
None	-0.28	0.22	n.s.	-0.42	0.12	***
R^2	0.076			0.071		
Adj.R^2	0.045			0.037		

Unstandardised regression coefficients (B) and standard errors (SE).
n.s. (non-significant). p< 0.001 ***

[41] For the regression analysis, *government*, *industry*, *both* and *none*, were included as dummy variables. Government was used as the reference category.

7.4. The role of demographics and CC risk perception in support for green ammonia technologies

The main objective of this research is to understand public perception of ammonia-based systems in two different contexts – Mexico and the UK. Taking into consideration this previous statement, further analysis was performed to determine the relationship between different factors when supporting green ammonia energy technologies.

Most of the respondents in both countries strongly support or somewhat support the development of green ammonia technologies (*UK M = 3.97 SD = .81*) (*Mexico M = 3.93 SD = .89*). Therefore, a linear regression was run to understand the support for these technologies and analyse the effect of CC risk perception (worry and threat), perception of risk/benefits, as well as affective responses on support for green ammonia technologies (see *Table 7.10*).

Results from a series of linear regressions indicate that CC worry, CC threat and perception of risks/benefits each separately and significantly predict support for green ammonia technologies with some exceptions as detailed below.

In the case of CC worry, a linear regression established that greater worry about CC significantly predicted greater support for ammonia technologies in the UK, $B = .153$ (.044). Worry about CC accounted for 3.1% of the variance, ($F(1,351) = 12.20, p = .001$). However, this was not the case for the Mexican sample, $B = .086$ *(.049)*, where no significant relationship was found between variables. The dependant variable only accounted for a non-significant 0.4% of the variance in this country, $(F(1, 559) = 3.142, p = .077)$.

For CC threat (to themselves, their families, developing countries and developed countries) a significant result was found in both countries. Greater perception of threat significantly predicted support for this type of technologies; Mexico, $B = .156$ (0.60), UK, $B = .233$ (.055). For the British sample, CC threat accounted for 4.6% of the variance, ($F(1,349) = 17.966, p < .001$), whereas in Mexico the explained variance was only 1.0 %, ($F(1,558) = 6.825, p = < .01$).

Similar results were found for perception of risks and benefits of the technology[42]. Data suggests that this independent variable highly predicts support for green ammonia technologies in both countries; Mexico, *B*= .613 (0.043); UK, *B*=*.475* (.055). Greater perception of benefits about green ammonia predicted support for the technology. Risks and benefits accounted for 26.5% of the variation in support for green ammonia technologies in Mexico, (*F(1,555) = 201.419, p < .001*), and 17.7% in the UK, (*F(1,347) = 75.837, p < .001*).

Affect towards green ammonia was similarly predictive of support for the technology in the UK (*B*= 0.467 (0.032)) and Mexico (*B*= 0.336 (0.031)). The more positive respondents felt about green ammonia, the more supportive they were of the technology. Affect accounted for 17.3% of the variation in support for green ammonia technologies in Mexico, (*F (1,560) = 116.921, p < .001*), and 38.5% in the UK, (*F(1,350) = 218.614, p < .001*).

Subsequently, a multiple regression analysis was run including the four theoretical variables mentioned above (CC worry + CC threat + risks and benefits + affect). The multiple regression model significantly predicted support for green ammonia technologies in both countries; Mexico, *F (4, 551) = 70.210, p= < .001* and UK, *F(4,338) = 73.158, p= < .001*. When taken together, the two climate change perception variables do not seem important for explaining support or opposition towards green ammonia technologies, but perceptions of risk and benefits as well as affective responses are strongly predicitve. CC threat was marginally significant (*p* = .049) in the UK only.

Regression coefficients, standard errors and R^2 and adj.R^2 can be found in *Table 7.10*. (below) For Mexico 34% of the variance in support is explained by these two variables (risk/benefit perceptions and affect). For the UK, a substantial 46% of the variance is explained.

The slope coefficient for CC worry was not statistically significant anymore for neither of the two countries. CC threat was still significant for the UK but not for Mexico. However, perception of risk and benefits of the technology statistically predicted support for green ammonia technologies in both countries. Regression coefficients, standard errors and R^2 and adj.R^2 can be found in *Table 7.10*. (below)

[42] Dependent variable: Would you support or oppose the use and development of green ammonia technologies in your country as a way to reduce carbon emissions? + Independent variable: Do you think there are more risks or benefits for green ammonia?

Table 7.10. Linear regression analysis of CC risk perception on support for green ammonia technologies

	Mexico			UK		
Independent Variables	***B***	**SE**	**p**	***B***	**SE**	**p**
CC worry	-0.017	0.049	n.s.	-0.012	0.047	n.s.
CC threat	0.067	0.061	n.s.	0.117	0.059	*
Risk and benefits of ammonia systems	0.506	0.044	***	0.294	0.047	***
Affect towards green ammonia	0.223	0.030	***	0.398	0.032	***
R^2	0.338			0.464		
Adj.R^2	0.333			0.458		

Unstandardised regression coefficients (B) and standard errors (SE).
n.s. (non-significant). p < 0.05*, p < 0.01**, p< 0.001 ***

When considering sociodemographic variables: gender, age, working status and political orientation, the model significantly predicted support for green ammonia technologies in both countries; Mexico, $F(5,473) = 2.826, p < .05$; UK, $F(5,279) = 3.034, p < .05$ (see Appendix C.9b for regression coefficients and standard errors). All five variables accounted for 3.1% (Mexico) and 4.5% (UK) of the variation in support.

Both, age and working status, did not predict support for ammonia technologies; however significant results were found for gender, women respondents are less likely to support green ammonia technologies in both countries.

Results from political orientation were only statistically significant in Mexico, $B= 0.055$ (0.018), showing that respondents leaning more to right-wing parties are more likely to support this type of technologies. This result goes in line with the current political situation in Mexico (see *Chapter 4* – political context) where the current government (left-wing) has continuously proclaimed against green energy technologies.

To conclude, a final multiple regression was performed including all variables (sociodemographic and theoretical). The multiple regression model significantly predicted support for green ammonia technologies for both countries, Mexico, $F(9,466) = 26.720, p= < .001$, UK, $F(9,267) = 28.445, p= < .001$. All variables accounted for 34.0% (Mexico) and 48.9% (UK) of the variation in support.

When considering all variables only gender, political orientation (only for Mexico), and perception of risk and benefits as well as affect have a significant relationship with support for green ammonia technologies, as displayed in *Table 7.11*. It does not appear that socio-demographic variables add significant explanatory power to the model.

Table 7.11 Linear regression analysis of support for green ammonia technologies (sociodemographics + theoretical variables)

		Mexico			UK		
	Independent Variables	***B***	**SE**	**p**	***B***	**SE**	**p**
Socio-demographic variables	Gender[43]	-0.153	0.067	*	-0.293	0.077	***
	Age	-0.028	0.033	n.s.	-0.005	0.032	n.s.
	Working Status (Unemployed)						
	Employed	-0.032	0.148	n.s	-0.096	0.159	n.s.
	Student	-0.042	0.177	n.s.	0.061	0.182	n.s.
	Political Orientation	0.044	0.015	**	0.003	0.017	n.s.
Theoretical Variables	CC worry	0.044	0.053	n.s.	0.027	0.053	n.s.
	CC threat (you and your family, your country, developing country and developed countries)	0.039	0.063	n.s.	0.103	0.067	n.s.
	Risk and benefits of ammonia systems	0.487	0.047	***	0.234	0.051	***
	Affect towards green ammonia	0.205	0.034	***	0.427	0.036	***
	R^2	0.340			0.489		
	Adj.R^2	0.328			0.472		

Unstandardised regression coefficients (B) and standard errors (SE).
n.s. (non-significant). $p < .05$*, $p < .01$**, $p < .001$ ***

7.5. Summary

This chapter intended to offer an analysis of the results obtained in the survey distributed in Mexico and the UK as part of the last phase of the research (Phase 2: Part 2). The study in this chapter has explored perceptions related to CC, energy sources and green ammonia.

CC concern has been increasing over the past years all around the world, countries are starting to pay more attention to this topic and actively looking for ways to tackle CC. Results obtained for the first block of questions in the survey are in line with our initial hypotheses about the existing concern about CC in the sampled countries. Respondents from both countries believe the climate to be changing, feeling a high concern about this topic (extremely or very worried) and stating that CC is caused entirely or mainly by human activity.

When analysing the impact of CC, results indicate that the UK has a lower risk perception for themselves and their country than the Mexican sample, however both countries perceive CC as a very or extremely serious threat for developing countries. Additionally, both countries agreed that it is the national government that is mainly responsible for acting on this issue, followed by industry.

[43] Gender coded as: 0 (Male), 1 (Female)

With regards to CC understanding, we can affirm that in general there is a good base-line knowledge around this topic in both samples. We observed this throughout different sections of the survey. Firstly, when asking about fuels, respondents in both countries tend to understand the impact of fossil fuels, opposing their use to generate electricity. Additionally, there is a good understanding of the low impact of renewable energy on the environment, showing high support for these types of technologies. Secondly, when presenting different statements to measure their CC knowledge (physical characteristics, causes and consequence knowledge) most of the questions were answered correctly.

However, even though, there is a good base-line knowledge we also noticed high uncertainty. Firstly, when talking about energy sources, data presented indicates that people "don't know" if biomass, biofuels and hydrogen contribute or not to CC which led them to be neutral about their support/opposition. Interestingly, nuclear power shows a different outline than fuels presented previously, most of respondents got both questions about this topic wrong, they believe it contributes to CC and that nuclear plants produce CO_2 during their operation, with both countries opposing its use. Nevertheless, Mexico showed a higher percentage of respondents supporting this technology compared to UK respondents.

In the FGs we noticed high concern about overpopulation amongst Mexican respondents, therefore we decided to include one question analysing this idea specifically about limiting the number of children per family as a measure to tackle CC and compare the perception between countries. Data obtained agrees with previous results, a majority of Mexican respondents agree with limiting the number of children per family whereas British respondents seem to be more neutral about this topic. It is important to highlight that most of the Mexican respondents were from Mexico City, one of the largest cities in the world, hence the impact of overpopulation is likely to be more salient and directly affecting them (The Guardian, 2016); a possible explanation for their strong support to limiting the number of children per family.

The main objective of this research was to understand and analyse first associations with green ammonia to produce and store energy. Throughout the research (FGs) we noticed a negative/neutral association with the term 'ammonia' and results in this survey were in line with this initial finding. When asking *What is the first thing to come to mind when you hear the word ammonia*, at the beginning of the survey, most of respondents in both countries answered using broad concepts like "chemical" or "chemical compound/substance" but also the second highest answer was focused towards negative concepts like 'poison' 'toxic' 'corrosive' or 'acid', indicating negative affect and risk perceptions towards this chemical.

This association was different when the concept of green ammonia was presented to respondents, while people in Mexico and UK had a negative/neutral idea of ammonia at the beginning, on the last section of the survey, the perception of the technology was positive, describing it as 'promising' 'beneficial' and ‘great idea’. This was also evident when most of Mexican and British respondents affirmed to feel extremely, moderately or slightly positive about the technology. In general, we noticed that Mexico seems to have a more positive perspective of the technology and more confident about the benefits. Nevertheless this country is also more worried about the risks than the UK, indicating more extreme perceptions for both risks and benefits.

This chapter has also explored perceptions of the development of green ammonia in the respondents’ country. UK and Mexican respondents strongly support or somewhat support the development of this technology in their country, additionally a majority believes it is feasible to develop.

However, in the case of Mexico, even though a majority answered it was feasible, a large number of respondents (just slightly less) were not sure. A possible explanation might be related to the last question of the survey where we observed a lack of trust in the government. Mexican respondents indicated they trust industry to develop this technology but not the government alone.

Trust was one of the results with a higher contrast between countries with 29.7% of British respondents trusting the government and only 3% in Mexico. Whereas the Mexican sample trusts the industry to develop this technology (44.6%), in the UK the trust relies in both institutions (43.8%).

Research shows that government and parliament are one of the institutions least trusted in the UK (OECD, 2017b). Additionally, Edelman Trust Barometer Report (Wisniewski, 2020) indicates that with regards to technology, British tend to perceive the industry as “essentially self-serving and just acting in their best interests”. This might explain the results obtained from the sample in the UK, where trust in the industry alone was the lowest response (4.8%) but a combination of both (industry and government) got the higher percentage (43.8%).

On the other hand, in Mexico, the government in power has in various occasions pronounced itself against renewable energy. Before the survey was distributed, Andres Manuel Lopez Obrador (Mexican President) announced his support for fossil fuel-derived power generation and a reduction in the budget for all green energy technologies (Fernandez, 2020). This context in the country explains the low trust from respondents in the Mexican government to develop green ammonia energy technologies.

Additionally, this chapter also aimed to explore the relationship between theoretical and demographic variables in support for green ammonia technologies. Interesting results were found when analysing these correlations further.

Concern about CC, perception of CC threat and risks/benefits of the tecnology, each separately and significantly predicted support for green ammonia technologies in both counries[44]. Interestigly, when combining these three variables, results indicate that the perception of risks/benefits and , as well as affect, mediate the association between CC worry/threat and support. Which indicates that support for this type of technlogy highly depends on the way particiapants perceive the benefits and the risks, and their affect associated with the technology. This is in line with Huijt et al's (2012) model, which suggests these variables are important for explaining acceptability (i.e. attitude) towards energy technologies.

Also, when examining trust linked to support for green ammonia technologies, we found a significant relationship between these two variables as would be expected. Results indicate that trust in at least one of the institutions, either government or industry, predicts support. When respondents do not trust any of them, support for this technology is considerably low.

In terms of demographics, results indicate that women respondents are less likely to support green ammonia technologies in both countries. These results go in line with different studies from previous years in the UK. According to (Devine-Wright, 2007) women are more likely to support new renewable energy development in general terms. However, when it comes to specific renewable technologies, women are less likely to support them (e.g. wind firms, nuclear energy, carbon capture and storage) (BEIS, 2020).

Additionally, results suggest a correlation between political orientation and support for green ammonia technologies amongst Mexican particiapants; respondents leaning more to right-wing parties are more likely to support this type of technology. This result reinforce the previous statement about the current situation of the Mexican government (left-wing) where the energy strategy is focused on boosting hydrocarbon fuels in order to support the national oil production.

7.6. Limitations

There are some limitations to this research phase that need to be addressed. First, when distributing the survey online (mainly on social media) we were unlikely to have reached all parts of the population, likely focusing on a younger audience. This is reinforced by the fact that respondents were recruited by snowball sampling which possibly caused people to share the survey with mostly people their own age. As mentioned in the methodology section, the recruitment process started with the researcher distributing the survey to colleges and then pass it on to friends and then other people, which might explain the large number of respondents in both countries between ages 25-34 years (age of the researcher).

[44] Except for CC concern for the Mexican sample where the relationship was not significant.

Additionally, distributing the survey through email and social media excluded a significant part of the population in Mexico, where only 56.4% of households have access to internet either from a computer or a mobile device (INEGI, SCT, 2020). This limitation and how it may have influenced the findings will be discussed in more depth in Chapter 8.

Regarding the survey, both of the samples were not representative of their country so it is important when considering the results that this data only represents a subsection of the population and not the view of all the citizens; therefore, an additional study with a larger sample should be carried out to obtain more representative data. Moreover, we were able to compare the UK data to other previous surveys and thus explore to what extent the current sample is similar or not to findings in more national surveys (on key perceptions like CC), however this was not possible for the Mexican sample because there are limited national surveys on these topics.

Furthermore, perceptions of green ammonia must be interpreted cautiously because of the novelty of the concept and lack of theoretical research. This was an initial first study and several topics could have been analysed further. Perception will highly depend on how much and what type of information is provided to respondents. Therefore, additional research should be carried out to determine the positive opinion of green ammonia obtained in the research and to what extent it changes when different kinds of information are presented.

Moreover, a couple of months after the survey was released, an explosion of ammonium nitrate in Lebanon took place with an extensive international coverage in media. Although the technology presented in this survey is different from this chemical that caused the explosion in Beirut, public perception could have been impacted and the support for green ammonia could have changed.

Chapter 8. FURTHER DISCUSSION AND CONCLUSION

8.1 Introduction

This final chapter summarizes the findings obtained from the research and discusses its implications. The chapter is structured around the three main research objectives and how these have been explored and addressed.

First, findings are combined from the two research phases with the general public in Mexico (Focus Groups and survey) to explore perception of laypeople regarding green ammonia. Later, this first section provides a detailed analysis of general results both, Mexico and the UK, linked to research presented in the literature review. Second, the chapter discusses how the sociocultural context shaped the perceptions of the technology in the UK and Mexico. Third, key risk and benefits perceptions of experts and general public are compared. These three sections of analysis provide an examination based on the theoretical framework presented on the literature review (*Chapter 3*).

The chapter goes on to discuss general limitations in two subsections: (1) conducting a cross-national study (2) methodological limitations. Later it provides detailed suggestions for further research throughout for sections (1) Perceptions of different samples and groups of stakeholders (2) Psychological factors explaining public acceptability and acceptance of green ammonia (3) Other forms of social acceptance: from the national to the local, and (4) Information provision and framing.

It concludes with specific recommendations for stakeholders and developers of green ammonia. General conclusion are also presented at the end of the chapter.

8.2 Further discussion and implications

The final analysis of this thesis will consist in the detail examination of the results presented in *Chapters 5,6* and *7*, based on the main objectives described in *Chapter 1* (see *Figure 8.1*):

- *Objective 1*: Understand people's perceptions and concerns about ammonia as an energy vector and for energy storage in the context of climate change. In particular, the project examines people's perceptions of the technology and its uses, its governance, and societal implications.
- *Objective 2*: Explore how key public perceptions of green ammonia differ across two different socio-cultural contexts (Mexico and the UK).
- *Objective 3*: Compare key risk and benefit perceptions between experts and the public.

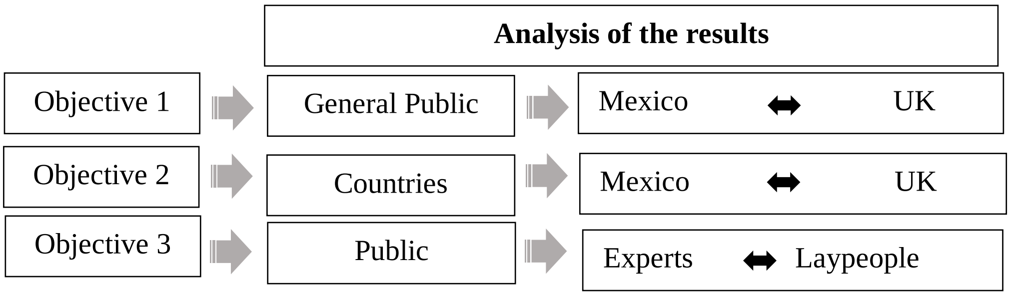

Figure 8.1. Diagram of results' analysis by objective.

This study represents the first empirical study on green ammonia in Mexico and the UK, exploring three main themes around it – first associations, benefits and risks, and trust. This research provides an opportunity for further work to deepen the analysis of underlying drivers of engagement and concern and investigate further the role that other social variables may have in this context. Therefore, due to the current limited data around this subject, this research is largely descriptive and aims to contribute to baseline understanding of the emerging technology of ammonia as a fuel and for energy storage.

8.2.1 Objective 1

Understand people's perceptions and concerns about ammonia as an energy vector and for energy storage in the context of climate change. In particular, the project examines people's perceptions of the technology and its uses, its governance and societal implications.

For this first objective, the research involved data collection through two collection tools in Mexico (FGs and surveys) and one collection tool in the UK (surveys). Therefore, this section will be divided in two subdivisions. First, we will combine the results from the FGs and surveys in Mexico to get a sense of whether they reveal the same about public perceptions of green ammonia and climate change. Subsequently, we will present a broad analysis of public perceptions of ammonia as an energy vector and storage method, considering findings from the UK survey as well.

8.2.1.1 Combining Focus Groups and Surveys Results in Mexico

Results from the FGs (phase 2.1) and the survey in Mexico (phase 2.2) reveal several similarities in terms of public perceptions of ammonia. For both phases the structure of the protocol and questionnaire were similar, which allowed us to compare results from these two different methodological approaches.

Both the focus groups and the survey included questions to gauge people's first associations with ammonia as a term and green ammonia after some initial information provision. Analysing findings from these provides indication of people's risk and benefit perceptions as well as affective responses

Huijts et al., 2012. The findings show that the word *ammonia* produced negative affect in people, nonetheless participants' reactions when presenting the concept of *green ammonia* were positive in both the FGs and survey.

However, there is an important difference that needs to be noted. In the survey we observed that Mexican respondents described the technology using words such as *promising*, *beneficial,* and *amazing*, as detailed in the results section of *Chapter 7*. However, the FGs reflected a more sceptical response; participants also used positive adjectives to describe the technology such as *interesting* and *sounds like a good idea*. However, this was followed by a "but" involving questions and concerns, for example about the water usage of the technology. Nevertheless, if we analyse further the results from the survey, the answers also reflect some doubtful perceptions (see *Chapter 7*, Figure *7.13*). The most common answers for the open question "*Please tell us what thoughts or images came to mind when reading this information about green ammonia*?" amongst Mexican participants were general positive words (as described above) followed by "novel concept" "solution/alternative for the environment" and "sceptical comments".

This difference between FGs and the survey could have been caused by two main factors. First, due to the nature of the data collection method. As described in *Chapter 4*, survey respondents are limited to one answer whereas FGs allow participants to express their thoughts more freely and allows the researcher to capture additional thoughts and feelings. This means participants were able to voice their concerns before expressing an opinion of green ammonia during FGs, allowing the researcher to also capture uncertainty in perceptions.

For the FGs, each group was presented with one slide with information about green ammonia explained by the researcher. On the other hand, in the survey, information about the technology was designed based on the FGs and was presented as a text and as an image. This means that respondents did not have a time limit or social pressure to read the information provided and were able to go back to the information several times in case of doubts before responding.

Subsequently, regarding the analysis of risks and benefits perception, both the FGs and survey presented to participants a list of benefits and risks of the technology for them to discuss and decide which one was more important for them. Answers amongst Mexican participants were the same in both phases; the main worry was about NOx particles and intensive water use of the technology and the main benefit was in FGs "the potential to tackle CC" and in surveys "that it would not contaminate the environment".

Support for developing green ammonia in Mexico was analysed next, answers in Mexico were again similar; in favour of the development of the technology but sceptical of the likelihood to have a technology like this in their country. This was followed by analysing *trust* which reinforced the answers from previous questions. Most of Mexican participants affirmed to not trust the government to develop this technology. This point is discussed further in the next objective focusing on the differences and similarities between Mexico and the UK.

8.2.1.2 General analysis of public perception of green ammonia

As mentioned previously, this study represents the first step into a comprehensive vision for the deployment of green ammonia as a fuel. When this research started in 2018, few green ammonia projects were in place around the world. However, three years later, the number of projects has been increasing and as stated in *Chapter 2*, it is expected to keep growing due to the potential of this chemical to transport hydrogen (Tullo, 2021). This highlights the importance of the results presented below regarding public perceptions of ammonia as a fuel. Additionally, due to the lack of research in this area, findings throughout this research represent an important contribution to this body of knowledge.

After understanding the results obtained in Mexico, we will continue with a general analysis of the data obtained from the general public in both, Mexico and UK. We will describe and analyse further the most relevant results obtained for green ammonia in the context of CC, linking these results to the existing literature presented in *Chapter 3*.

With regards to CC understanding, we concluded that participants have a good baseline knowledge around this topic. However, there is still high uncertainty around which fuels contribute to CC. Interestingly the fuel that laypeople have more doubts about is hydrogen. These results are in line with data obtained from (Sherry-Brennan et al., 2010) who analysed public attitudes towards the use of hydrogen energy in the UK; results indicated that the largest portion of the sample expressed a low or very low level of knowledge about hydrogen.

This low level of knowledge about hydrogen is important for this research because ammonia fuel is based mainly on hydrogen. Thus, this implies that if the technology is presented to general public, a majority might not consider hydrogen as carbon-free. This may be an important focus for future communication around green ammonia technologies.

Additionally, a study presented in *Chapter 3*, from Flynn et al. (Flynn et al., 2010) also presented similar conclusions about hydrogen. They carried out a study about public perception of hydrogen energy through FGs in England and Wales. First, people were asked to discuss general aspects of the environment and energy production. Afterwards, attendees discussed hydrogen in more detail. When hydrogen technologies were explained, participants' reactions were neutral, neither expressing full support nor opposition, pointing out that acceptability of these technologies could only be possible when comparing it with other alternative energy systems in terms of costs, safety and risks.

This previous research is relevant because most of our respondents from the UK were located mainly in England and Wales and this research reflects similar results. When asked about support/opposition of hydrogen as a fuel, a majority of British participants remained neutral (46.9%) and also a majority declared not knowing if it contributes or not to CC (42%). Even though there are no formal studies about public perception of hydrogen in Mexico, results from the FGs and survey indicate that also a majority of Mexican participants do not know if this fuel contributes or not to CC (35.7%) and a high number remain neutral (don't know: 23.2%).

Therefore, taking into consideration the results from the FGs, survey and based on the conclusion of Flynn et al. regarding hydrogen – acceptability of these technologies is likely to depend on a number of other factors such as judgements of specific risks and benefits compared to alternative energy systems. This is further explored in a later section on future research.

When analysing specifically results obtained from public perceptions of green ammonia, we concluded that in general, participants' perception of the technology was positive. This was also evident when most of them affirmed feeling extremely, moderately or slightly positive about the technology in the surveys. Positive results need to be analysed carefully due to additional factors that could have influenced public's perception such as *preference construction*, *framing* and *technological optimism*. These will now be discussed in turn.

Based on the literature we understand that even though green ammonia is an emerging technology and participants might not have been familiar with the topic, their responses are part of the concept described in *Chapter 3* as 'preference construction'. Therefore, due to the novelty of green ammonia, first associations might have not been linked to knowledge but rather to an initial affective response (Pidgeon et al., 2012)

Throughout this research we did not evaluate specific beliefs or values related to the technology, however, when analysing first associations with the word "ammonia" and then with "green ammonia" we were able to observe the types of perceptions that are likely to influence people's initial preference construction process. For instance, for the word *ammonia* 18.4% of the responses were aware that it was a chemical, however, a large percentage of the total sample (17.4%) described it using more subjective terms, such as *poison*, *toxic*, *not safe* or *bad for humans* – indicating negative affect and risk perceptions are also in people's minds when thinking about this chemical. In both countries, negative initial responses to the term ammonia were not indicative of their reactions to green ammonia however.

A majority of people in both countries (Mexico 30.2%, UK 39.5%) has positive affective reactions to the idea of green ammonia (e.g. “promising” “beneficial” “amazing” “great idea”).

The role of *framing* is also important to consider when analysing the positive evaluations of the technology. During the FGs and the surveys, participants were presented with information about green ammonia framed in the context of CC; this could have impacted their responses, obtaining a positive outcome. Looking at the literature presented in *Chapter 3* about framing (Whitmarsh et al., 2019) (Hayashi et al., 2016) both studies have demonstrated that providing information, either sustainability information about the technology or framing it around CC, plays an important role in public’s support. Generally, such framing leads to more positive responses than framings that attempt to remain neutral. For example, results from a study on public attitudes towards fusion energy in Europe revealed that awareness of fusion energy was low to moderate, however attitudes regarding the technology were generally favourable. The study reveals that raising people’s awareness on topics like CC, affordability and sustainability benefits of the technology might lead to positive perceptions (Jones et al., 2021).

In this study, CC was part of the framing of the information about green ammonia because it is being developed as a low-carbon fuel in order to reduce carbon emissions. Therefore, considering our aims it is important to understand how this informs their opinion on ammonia technologies that are presented to them. Any future communication about green ammonia is likely to include information on climate change and it’s low-carbon characteristics as well. Future research examining different framing or informational scenarios are considered later in this chapter,

On the other hand, the literature also suggests that positive responses towards the technology from laypeople in FGs and surveys might have been due to a concept named ‘technological optimism’ – the positivistic belief that all phenomena harmful to humans, can be fixed or overcome by a certain technology (Kerschner & Ehlers, 2016). This means that new technologies are often perceived positively because people have a lot of hope for it to solve problems, for example climate change. This type of technological optimism was also evident in the literature on hydrogen, whereby people generally had positive initial reactions to hydrogen but asked for further information to make up their minds (Flynn et al. 2010). This finding could explain the high percentage of participants supporting ammonia technology in this research as well. Nonetheless, it is important to recognise that this only represents an initial reaction to the technology, and other factors are likely to become important to determine ultimate acceptance of the technology (e.g. support for specific projects or applications). As *Chapter 3* has shown, technologies may be viewed positively at an abstract level but additional factors become important at the local level e.g. when technologies are developed and deployed in a particular place (Wüstenhagen et al., 2007). It is too early to tell exactly what public responses will be when green ammonia is deployed in a specific context, but this is an avenue of future research that needs to be explored further. One particular area for further research should be around specific applications, such as in the maritime industry, to explore whether some applications are more or less acceptable to people.

The research has also elucidated the kinds of risk and benefit perceptions that are likely to impact on people's acceptability and acceptance of green ammonia in the future. Perceptions of benefits associated with green ammonia revealed that people felt most positive about it being a low-carbon fuel, followed by the fact that animal waste could be used to produce energy, and that there is established infrastructure around the use of ammonia. The benefit of ammonia's smell in helping detect leaks was considered least positive of all the benefits mentioned. Benefit perceptions tended not to differ across the two countries.

Perceptions of risks did however differ across countries. For UK respondents, the main worry was about possible NOx emissions if ammonia is not burned properly, whereas, in Mexico, their main concern was about the intensive water use of the technology. While the difference between countries will be addressed in *Objective 2*, it is important to highlight that water intensity was a worry for Mexican participants in both, the FGs and the survey.

The second highest worry in the UK was the toxicity of the gas when inhaled, while Mexican participants opted for NOx emissions. Interestingly, the possible increase in electricity prices seems not to be a main worry for neither of the countries. The unpleasant smell came as the least of the worries for both Mexico and the UK. It appears that smell is not a particularly important aspect for public perceptions, at least when evaluating the technology at a general socio-political level. This answer is relevant for the analysis in *Objective 3*, where we will compare this response to the perception of experts (who did stress the importance of smell as a benefit).

Trust is another important factor for understanding public perceptions of emerging and low-carbon technologies. Trust has been found to be particularly important when people have little knowledge or familiarity about a risk topic (Siegrist, 2021). Our findings on trust show quite significant differences across the two countries: whereas the Mexican sample trusts the industry the most to develop this technology, the UK sample would rely on both government and industry (this comparison between countries is analysed further in *Objective 2*). Nonetheless, Mexican focus group participants were relatively sceptical about the feasibility of developing green ammonia because neither industry not government were considered particularly committed to addressing climate change. This is a significant barrier for gaining public support to develop the technology further. It seems that people are positive about the benefits of green ammonia, but the lack of trust in stakeholders may increase risk perceptions and decrease benefit perceptions in the future. The lack of trust is therefore significant, and if not addressed, could jeopardise public acceptability of green ammonia, especially in Mexico (Bronfman et al., 2012).

One stakeholder that was not included in the research is the role of an independent regulator and future research should examine whether other types of stakeholders can improve trust for the development of green ammonia. As discussed in chapter 3, trust in other stakeholders such as developers (Jones et al., 2018) is likely to become increasingly important also at the local level as specific technologies are applied and implemented in a specific location.

The regression analysis as part of the survey enabled an initial exploration of how different cognitive and affective psychological factors influence support for green ammonia technologies, specifically risk/benefit perceptions, as well as affect towards green ammonia. The analysis found that if people perceive more benefits and feel more positive about green ammonia, they were more supportive of the technology. This is in line with the theoretical models reviewed in chapter 3 and underline the importance of looking not only at how people perceive risks and benefits specifically, but their overall 'gut feelings' which are used heuristically to come to a conclusion about the technology, especially when participants know very little about it (Siegrist et al., 2014). We also included a number of climate change specific variables (worry and threat perception), but these were not important for explaining support.

Finally, socio-demographic factors were also included in the analysis as they have been found to be important for understanding public acceptability of low-carbon technologies (Huijts et al., 2012). On the whole, socio-demographic variables were not particularly important for explaining support for green ammonia, but they did reveal differences in terms of gender. Male participants were more likely to support the technology in both countries. These results are in line with different studies from previous years in the UK. According to (Devine-Wright, 2007) women are more likely to support new renewable energy development in general terms. However, when it comes to specific renewable technologies, women are less likely to support them (e.g. wind firms, nuclear energy, carbon capture and storage) (BEIS, 2020). A study carried out by Pew Research Center suggests that men are more optimistic than women about future technological changes (Smith & Gao, 2014). Additionally, research shows that women are more risk averse than men (Buračas, 2012). For instance, results from the AcceptH2 study – research for the introduction of hydrogen bus trials, revealed that in Berlin and London significant relationships were found between gender and associations to hydrogen. In Berlin men gave more positive answers than women. However, this was not the case of London, where women answers were more positive. The authors cite another study supporting the results obtained from Berlin, stating that previous research highlight negative associations with hydrogen tended to be given by women Dinse (2000) as cited in

(Siegrist et al., 2007) also found similar results on perceptions of nanotechnology hazards. Gender was significantly correlated with perceived risks for this technology, where women had higher risk ratings than men. Similar results have been observed in numerous studies (Joubert et al., 2020) (Simon, 2010). Therefore, we conclude that men are more likely to support the technology because they perceive less risk in emerging unfamiliar technologies (Cherryman et al., 2008), such as green ammonia, whereas women are more cautious. Similar results were obtained in research carried out by the UK Energy Research Centre (Cox & Westlake, 2022) about public perceptions of hydrogen produced using electrolysis with renewable energy. Results reflect that high-income males were more likely to support the technology than women.

8.2.2 Objective 2

Explore how key public perceptions of green ammonia differ across two different socio-cultural contexts (Mexico and the UK)

Under the previous objective, public perceptions of green ammonia in the context of CC were discussed. This objective focuses on the differences between the two socio-cultural contexts in which the research was carried out: Mexico and the UK. First, we need to remember that Mexico was chosen as one of the countries for this analysis due to the (1) well-established knowledge and infrastructure around ammonia and because (2) the research was funded by the Mexican government (National Council of Science and Technology – CONACyT). The UK was chosen as a second country in this study (1) due to the potential of green ammonia as a storage method for excess energy from renewables.

This objective was analysed through a survey distributed in both countries to compare key perceptions across Mexico and the UK and gain a better understanding of how the national and socio-cultural context may shape views about green ammonia.

As stated in *Chapter 4,* the impact of culture on people choices – what societies choose to call risky– is determined by social and cultural factors (Breakwell, 2014). Therefore, in order to take appropriate actions regarding concerns from public we must recognise and analyse the role of the embedded culture. According to Taylor A. et. al (2014) several cross-country comparisons about CC have demonstrated clear differences in people's beliefs and conceptualisation, allowing us to gain a better understanding of collective ideas. As Whitmarsh (2005) suggests that "Climate change is not simple a scientific issue, it is a fundamentally social, political, cultural and moral one. Understanding this topic, including causes, impacts and solutions must be accompanied by societies and economic, their values and lifestyle."

(p.14). Based on the literature to compare responses between countries, we will take the most relevant results regarding public perception of green ammonia and analyse them based on a socio-cultural basis.

The first section of the public perception analysis explored *first associations* with the word *ammonia.* Based on the results if we look at the data from each country separately, several differences between them were found. Results show that for the UK sample the most popular answer was associated with smell, followed by mentions of urine/manure and cleaning products. On the contrary, the most mentioned answers in Mexico were "poison" "toxic" or "acid", followed by just mentioning "chemical" and in third place, cleaning products. This indicates that perhaps in the UK, people have less negative affective responses to the thought of ammonia compared to Mexico. Smell is also an interesting aspect to examine further. In the UK this aspect came as a first thought when hearing the word *ammonia* but in Mexico was not very common (UK 25.2% Mexico 7.1%). During the FGs in Mexico "smell" was never mentioned and when the question was prompted the answers were "no, I don't mind" "I am not worried about it", making jokes about having worse odours around the city.

An explanation for the difference between countries regarding ammonia odour in the surveys could be that Mexican participants do associate ammonia with a penetrating smell but is not something that annoys them. According to the laws in the UK bad odour can be treated as "statutory nuisance" under the Environmental Protection Act 1990 (EPA), even being bother by the smell from a neighbour's house or garden can be addressed by the local council (UK Environmental Law Association, 2017). Whereas in Mexico there is no regulation for unpleasant smells (Santillan, 2021). This is also evident in the question about risk and benefits of the technology. When participants were presented with a list of benefits both countries opted for "penetrating smell to detect a gas leak" as the least favourite, however British participants were less positive than Mexican participants.

Regarding first associations with *green ammonia*, answers were similar between countries. Both answered with positive comments about this technology as mentioned previously. A high percentage mentioned positive comments relating ammonia with the environment. Nevertheless, sceptical answers about the technology got a relatively high response as well in both countries (Mexico 7.1% and UK 8.1%) stating that they don't believe in the graphic presented "I don't believe it" "Not sure it can work" "weird" "It will end up not working".

Participants were also asked to rate on a 7-point scale (from 1-extremely negative to 7- Extremely positive) how they feel about green ammonia to gain an indication of their affective response as this has been shown to be important for determining public acceptability (Renn & Benighaus, 2013) (Slovic et al., 2004). Responses from both countries were similar with a majority of the answers being positive.

However, Mexican participants felt slightly more positive about the technology than British participants.

The benefit participants feel most positive about in both countries is the zero-carbon property of this fuel, followed by using animal waste to produce energy and the stablished infrastructure. Nonetheless, for the second benefit mentioned (animal waste) a significant difference was found between countries, where the Mexican sample felt more positive about this advantage.

On the other hand, for risk perception, there was a significant difference for every presented risk. For UK participants the main worry was about possible NOx emissions if ammonia is not burned properly, whereas in Mexico their main concern was about the intensive water use of the technology. The latter result is in line with prior information obtained in FGs where one of the most common questions within FGs in Mexico City and Cancun was focused on the water needed to develop this technology.

This concern about water use can be understood in the context of water shortages in Mexico. Mexico City's water reserves are expected to dry out in the next 30 years due to inefficient and ageing water networks infrastructure. Additionally, according to the National Water Commission (CONAGUA) water shortages are common in some parts of Mexico, however, this problem has exacerbated due to extreme temperatures caused by global warming (NBC News, 2021): "Experts fear the problem will reach more of the 22 million inhabitants of Mexico City's metro area, which is quenched by a network of reservoirs. Some districts have no piped drinking water at the best of times." Furthermore, according to Rafael Sanchez Bravo, a water expert at Chapingo Autonomous University, in 2022 there will be a water crisis, since the reservoirs are completely depleted.

It is likely that these concerns were heighten by the information that participants received about green ammonia, which stated that in order to produce green ammonia, the hydrogen required needs to be obtained from water. These three aspects are important to consider in Mexico (or any other country with water shortages) for future research. In this scenario the technology's deployment could be jeopardized by a negative perception or low support if this threatens the water supply for the city or agriculture. This is explored further in the section on future research below.

In general terms when comparing both countries in the section of risks and benefits, we could observe that Mexico feels slightly more positive about the benefits than the UK. However, when we look at the risks, Mexico is also more worried about the risks than the UK, indicating more extreme perceptions in both of the questions. These results were confirmed when asked about how acceptable or unacceptable the risks are, where Mexican participants again tended to be more concerned about the risks than the UK. A possible explanation for this might be that despite the positive perception Mexican participants have about the technology, one of the biggest concerns in the country is about legislation and the lack of control from the government, which might explain why they are more worried than the UK about the risks. This was also confirmed further with the question of feasibility and trust to develop the technology.

When asked about the feasibility of developing green ammonia in their country, it is evident that Mexican respondents are more sceptical than UK respondents. In the UK a majority of respondents believe the technology is feasible, whereas Mexican respondents were much more divided. These findings can also be understood in the policy context of each country as presented in *Chapter 4*. The UK was the first major economy to commit to a net zero target (Shepheard, 2020). In 2021, the UK announced the new "Net Zero Strategy" to achieve this goal by using electrification, hydrogen and innovation (Carbon Brief, 2021). Therefore, it is evident that the government and industries are working towards a decarbonised society, adopting similar technologies. However, Mexico represents the opposite scenario. First, this country depends economically on oil and gas, therefore several investments have been made in order to modernise every oil refinery plant. Additionally, despite the potential of the country to generate green energy through renewables (as stated in one of the reasons to study Mexico), the current government has announced new reforms to hinder renewable energy projects and allow the Federal Electricity Commission (CFE) to prioritise electricity produced by state-run facilities using fossil fuel sources (Linthicum, 2021).

This difference in policy background in each country may also be contributing to the difference in trust that was observed between the two countries. For British participants the most trustworthy institution to regulate this technology is a combination between government and industry, whereas for Mexico the industry was their first option. Only 4.8% of people in the UK answered to trust only the industry, on the other hand only 3% of Mexican participants trust the government. Additionally, it is important to note that a large number of participants in both countries replied that they don't trust in neither of these actors to regulate it (UK 21.8%, Mexico 17.3%).

Considering the results from both countries about trust, further analysis was performed to understand the relationship between this topic and support from green ammonia technologies. A regression analysis established that trust in government predicts support for green ammonia technologies in both countries. For the UK, trust in at least one of the institutions also predicts support for green ammonia technologies. This is in line with the theoretical model developed by Huijts et al (2012), whereby trust predicts positive attitudes towards technologies.

Results from political orientation were only statistically significant in Mexico, showing that participants leaning more to right-wing parties are more likely to support this type of technologies. This result is in line with the current political situation in Mexico where the current president (AMLO) is from a left-wing party. Usually, left leaning governments will lean towards environmental values but AMLO is not; he cancelled planned energy auctions for renewable energy projects upon entering office.

8.2.3 Objective 3

Compare key risk and benefit perceptions between experts and the public

As it was highlighted in the introduction (*Chapter 1*) and literature review (*Chapter 3*), involving the public at an early stage is important for an energy technological development to facilitate its deployment. Experts and the general public most of the times perceive risks in a different way (Bostrom, 1997); this diverse perspective should be seen as a complementary tool for any development instead of a disadvantage.

Based on results from this research we can conclude that benefits associated with the technology from the general public and experts were similar. As mentioned in the previous two objectives above, the benefit laypeople feel more positive about in both countries is the *zero-carbon* property of green ammonia, followed by using animal waste to produce energy and the established infrastructure. Additionally, for both countries the least favourite benefit was the penetrating smell to detect a gas leak.

If we compare these answers to the experts' perception, we can observe several similarities; people working with green ammonia declared to be working with it due to the *zero-carbon* property of the chemical, mentioning this characteristic as the main benefit of the technology. They framed the answer as a solution for a problem – the problem being CC and the solution a carbon-free fuel. As a second aspect experts mentioned as a positive WAS the established knowledge about handling ammonia as a chemical.

However, when discussing *risks*, differences between the groups were found. For experts, this topic was discussed as *concerns*, *risks* and *disadvantages* associated with ammonia as a fuel or for energy storage. Whereas laypeople's main concern are *NOx emissions* and *water intensity*, for experts it is the *fuels market* and *costs*; NOx was not even a topic that they considered extremely relevant. Even when it was mentioned, toxicity was associated more with an issue for public perception and not the technology itself. When discussing *disadvantages* during the experts' interviews, "toxicity" and "NOx emissions" were mentioned. However, they mentioned toxicity as a negative aspect but mainly for the public, as mentioned before, rather than a disadvantage of working with it. They implied that it is something they can tolerate but the public would not.

Nevertheless, these results are not different from previous findings on emerging technologies. As stated in *Chapter 3*, (Siegrist et al., 2007) examined laypeople's and expert's perception of 20 different nanotechnology applications. Results showed that these two groups differ on how they perceive risks. According to this study, laypeople tend to perceive risks based on three aspects: trust, perceived benefits, and general attitudes, whereas experts based their risk perception on a hazard assessment without taking into consideration benefits.

Results obtained in this research regarding green ammonia align with the conclusion from Siegrist et al., where benefits are a significant factor for general public to support the technology (based on the results from the multiple regressions in the surveys). Answers from experts appear more focused on the technical aspects of the technology and their knowledge of how it works. Further work could examine this in more depth, for example using the psychometric paradigm as in the work on nanotechnologies previously mentioned. This would enable a closer examination of the different risk characteristics of green ammonia (e.g. controllability, uncertainty) and how they are perceived by laypeople and experts.

Another difference between experts and the general public appears to be the perception of *smell*. This is interesting because when comparing the answers from experts, they thought the public was going to be concerned about the smell, when actually results indicate that they are more concerned about water usage and trust to keep the technology safe (both for humans and environment) rather than the smell.

When talking about costs, the general public were asked how much extra they were willing to pay if they knew their electricity would come from clean sources. Responses included different percentages, however 4 out of 5 FGs were willing to pay more than 10% with two FGs stating they would pay above 50%. Perception of costs was not measured in the surveys; however future research could include a question about this topic.

On the other hand, for experts, costs were related to fuels and the difficulty of setting up a new technology in the energy industry comparing the current low costs of fossil fuels. Responses from experts during the interviews reflected upon the concepts described in *Chapter 2* about *technological lock-in* – how the development of a technology is influenced by the social, economic and cultural context in which it develops. *Institutional lock-in* – the high start-up costs for new technologies and difficulty of the institutions to change in order to allow new developments; and as well *carbon lock-in* – the difficulty for low-carbon technologies to play a role when there is a current system based on fossil fuels. All these factors were acknowledged during the interviews describing the current challenge of green ammonia to play a key role in decarbonisation.

Despite the several differences between general public and experts, there was another aspect that both groups highlighted as important for the development of the technology: *trust*. As pointed out in the analysis above for *Objective 1* and in *Chapter 7*, results from multiple regressions indicate that trust in at least one of the institutions, either government or industry, predicts support. When respondents do not trust any of them, support for this technology is considerably low. This is similar to experts in the sense that it was noticed throughout the interviews the importance of trust in the industry (market) and the government to overcome the lock-in discussed in *Chapter 3* and *5*, This was evident when experts pointed out the important role of industry and government when developing a new technology, especially when introducing a new fuel and the need of a mutual collaboration to make ammonia fuel possible and overcome the aforementioned market lock-in.

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This illustrates that *trust* is an important factor not only for the general public but also for experts. Consequently, our findings reinforce the current literature cited in *Chapter 3* about the importance of trust in emerging technologies.

Another factor that is worth noting is that when analysing concerns for experts, *public perception* was mentioned, with three interviewees being concern about the public rejecting the technology because they do not understand it. This was a very common conception from experts throughout the interviews. We could even state that the general public was seen as an impediment for the technology rather than a group to take into consideration.

These responses from experts are in line with the deficit model of public understanding of science ((Fiorino, 1990), where experts believe that people might be challenged to understand the technical nature of emerging technologies and as such fail to fully understand its value. Therefore, decision-making under this model should be left to elites such as experts in the technology.

These responses from the experts in our research and literature, highlight the importance of the study presented in this thesis. The general public should not be seen as an impediment of an emerging technology but as an enabler. As described in *Chapter 2* and *3*, lay perceptions should be taken into account in line with a responsible innovation framework, recognising the importance of joint work between key stakeholders. The research in this thesis has uncovered a number of concerns people have about the development of green ammonia, which need to be considered as part of the technological advancement process. Some of these relate to the actual development of the technology (e.g. water use), whereas other have implications for future communication as the technology matures and reaches commercial viability. These are discussed further below.

8.3 General limitations

This following section discusses general limitations of the current research. As mentioned previously, this is an exploratory first study in this area and aims to provide a basis for future research and development of the technology. The research conducted as part of this thesis provides initial explorations into public perceptions around this subject, enabling future stakeholders to consider the findings throughout the development of new technologies fuelled by NH_3. As a result, there is scope to advance the findings further.

8.3.1 Conducting a cross-national study

Chapter 4 presented the rationale behind a cross-national study for the specific topic of green ammonia, highlighting the importance of carrying out research comparing two or more cultures or nations. However, when conducting cross-national studies there are certain limitations that we need to acknowledge.

According to (Gharawi, Pardo, & Guerrero, 2009) cross-national studies encounter two general challenges: (1) issues and challenges that may affect the reliability and the quality of data being collected for comparative studies (2) remaining issues related to the research objective, the selection process of countries and the analytical strategy. Below, these two challenges are analysed on the basis of the current research of green ammonia.

8.3.1.1 Issues and challenges that may affect the reliability and the quality of data being collected for comparative studies

Translation – when collecting and analysing data from different countries, language is a big limitation; translation should be done cautiously considering not only good literal translation but also to achieve equivalence in meaning. As mentioned in different chapters throughout this thesis, the native language of the main researcher is Spanish, while also being fluent in English. Additionally, both supervisors are fluent English speakers, supervising all aspects of the translation. Nevertheless, we need to take into consideration that even though this challenge was acknowledged from the beginning of the research, some concepts could have been lost in translation, mainly during the focus groups (conducted in Spanish), where informal conversations were held, and several colloquialisms were used. For example, in Mexico curse words are used very often through informal conversations as adjectives (not as insults), this is inevitable if you want to capture participant's perceptions and feelings in this country. Therefore, it was important to have a native Spanish speaker from Mexico moderating and translating the FGs. For this reason, the translation was made very carefully and not only translating directly but also considering the tone and idea behind each statement.

In line with the statement above, experts point out (Gharawi et al., 2009) that another challenge for cross-national studies regarding translation is that the translator should be knowledgeable about the cultures involved and should also be familiar with the field of the research study. Hence, no external translator was used during this research and the main researcher completed all the translation process.

Samples – another challenge is to identify how closely the samples match the country for the comparability purposes (Salway et al., 2011). The results section of each phase addresses this challenge, both samples were not representative of their country so it is extremely important when considering the results that this data only represents a subsection of the population and not the view of all the citizens; therefore, an additional study with a larger sample should be carried out to obtain more representative data in the UK and Mexico. When achieving representative samples from the countries analysed, researchers can obtain insights and observations aligned with the entire population group.

Research instruments – when conducting a cross-national study it is important to also consider the impact and reliability of the research instruments utilised in each country. For example, (Gharawi et al., 2009) state that “a long and complex survey may be considered normal in most developed countries such as the USA, but complex and difficult to be used in countries where the education level is lower and there are different cultural norms”. In the case of the instruments utilised in this research we took into consideration the lack of national surveys on these topics in Mexico; therefore, we adapted the instruments to collect the necessary data to be able to make comparisons, for example, by planning FGs before the survey we were able to include topics of interest and importance for Mexican participants. We also chose questions suitable for both cultural contexts to increase comparability.

Nevertheless, as highlighted in *Chapter 7* we need to consider that distributing the survey through email and social media excluded a significant part of the population in Mexico, where only 56.4% of households have access to internet either from a computer or a mobile device (INEGI, SCT, 2020). Further research to evaluate this topic in Mexico is suggested, perhaps using other platforms in addition to online surveys, such as phone or mail surveys. Using additional instruments in this country will allow researchers to have a more representative sample and obtain results that reflect the perception of participants with a lower income or lower educational profile.

Financial resources – This aspect was a limitation to obtain a representative sample in both countries and also an impediment to carry out FGs in the UK to compare responses with the same methodology. Therefore, further research is recommended in this topic obtaining representative samples for both countries. Additional financial resources could be used to carry out a comprehensive study with FGs on public perceptions of green ammonia in the UK and achieve larger samples in the surveys.

8.3.1.2 Remaining limitations related to the selection process of countries and the analytical strategy

Countries of comparison – *Chapter 1* described the rationale behind the selection of each country. However, we need to acknowledge the clear differences between them and highlight the effect that this could have in the analysis of the results. Throughout this thesis several comparisons have been made between the UK and Mexico, nevertheless both countries, as stated in *Chapter 4*, have different types of economies. The UK is a developed nation and Mexico is a developing country (United Nations, 2021). This is relevant for different aspects but most importantly because of the impact of culture on people choices – what societies choose to call risky– is determined not by nature but by social and cultural factors (Breakwell, 2014). This aspect has been taken into consideration at analysing data according to a national context (presented in Chapter 4). Nevertheless, it is worth noting that one of our objectives is to understand the implications of green ammonia public perception in two different contexts.

This aspect could be considered a limitation due to the implications concerning the lack of scientific research on this topic in developing countries, such as in Mexico. The limited number of studies restricts the amount of data available to compare the results obtained in this thesis and therefore precludes drawing accurate conclusions for the country. As it can be observed in the results section and discussion, national statistics in the UK were used to compare data obtained in this research from British participants. However, this was not the case of Mexico, as there is not enough research to make comparisons where relevant. Therefore, it was more difficult to determine the reliability of the Mexican findings of this research.

Nevertheless, this is also one of the most important strengths of this thesis. Including a developing nation as part of the study is an important contribution to the body of knowledge around the area of public perception. (Balundė et al., 2019) argue that when researchers treat each nation as an object of analysis, comparing fairly similar countries may prove most useful. Therefore, most of the times research is carried out comparing developed nations, limiting the amount of information available from developing countries. For example, (Balundė et al., 2019) brings attention to the limited evidence of the relationship between people's values, environmental self-identity and pro-environmental behaviours across different countries and cultures because studies tend to focus on western European countries and the US.

It is important that public perception studies also take into consideration the role of emerging economies, such as Mexico, and therefore we suggest further research to continue to examine this topic in developing countries. This selection process will have major implications on the findings and will allow researchers to explore the scope or universality of a phenomenon.

8.3.2 Methodological limitations

8.3.2.1 Order of the questions and information provided

Results in this thesis suggest a positive response towards the use of green ammonia as a fuel and energy carrier. However, perceptions of green ammonia must be interpreted cautiously because of the novelty of the concept and lack of theoretical research. We have also stated through the discussion in *Objective 2* that perception will highly depend on how much and what type of information is provided to participants. Expanding on this point, future studies could analyse the impact of framing on green ammonia by providing one group of participants a text with a CC framing (like the one in this study) and other group, without the framing.

In this study CC was chosen as a framing because green ammonia is being developed as a low-carbon fuel in order to reduce carbon emissions. Therefore, considering our aims it was important to understand how this informs people's opinion on ammonia technologies that are presented to them. When using different framings, results might reflect different levels of support. One aspect that might be interesting to examine is to what extent support would differ when green ammonia is presented not as an energy carrier but as an option for the fertilizer industry.

Additionally, some studies have demonstrated that the order of the questions on an interview or a survey also influences the responses of participants (Sarniak, 2015): "respondents are primed by the words and ideas presented in questions that impact their thoughts, feelings and attitudes on subsequent questions" therefore, we need to acknowledge that interview protocol started with the topic of CC, fuels, PEB and concluded with green ammonia perception. This was designed in a specific way to get a better understanding of topics related to green ammonia, as one of the objectives clearly specifies "**understand people's perceptions and concerns about ammonia as an energy vector and for energy storage in the context of climate change".** Nevertheless, positive responses could have also been caused by this factor.

8.3.2.2 Sampling

There are also limitations in the recruiting process that we need to acknowledge. For the three stages of the research (P1, P2.1, P2.2) participants were recruited through contacts of the main researcher which might have caused a certain level of predisposed positive opinions. Below we explain the case of each of the phases.

Interviews – our recruitment process consisted of sending email invitations to participate in the study. The contact information was obtained from one of the supervisors in this research, Dr. Agustin Valera-Medina, who is currently working with green ammonia. This could have impacted the positive responses about the technology, highlighting the benefits and perhaps diminishing the risks. As highlighted in *Chapter 5*, perhaps the interview corpus could have also included a few more people from a different technology background to provide more critical views of green ammonia and look more in detail in the variation of the discourse. For example, from experts working with hydrogen and using green ammonias as a mean to transport energy. We recommend that future research take into consideration including experts working with different technologies, perhaps similar emerging technologies.

Focus Groups– participants were recruited through contacts in the community, in each location the researcher obtained one or more contacts which later passed the invitation to other members of the same community until the desired number of participants was reached. This could have caused the age and socioeconomic background of most of the participants to be similar. Additionally, some participants could have not expressed their opinions unreservedly due to the familiarity with the moderator (the main researcher). Further research should involve additional FGs with an independent researcher.

Survey – similar to the FGs, the recruitment process started with the researcher distributing the survey to colleges and then pass it on to friends and then other people, which might explain the large number of participants in both countries between ages 25-34 years (age of the researcher). This could have also impacted on the positive responses about the technology, as people around the researcher might be more incline to support this kind of technologies.

This aspect is relevant to highlight because the highest contrast between the sample and national data in the UK were people 65+. According to official data (ONS, 2018) 65+ people represent 18.3% of the total population, the largest age group in the UK. Whereas in the sample it was the opposite, representing only 6.7%, one of the lowest represented age groups in the survey. Therefore, if a representative sample is achieved, results are likely to change. For example, regarding political orientation the UK sample was clearly leaning more to the left; left-wing governments usually lean towards environmental values. However, older people tend to support more conservative parties (Inman, 2019), which indicates that a representative sample in this country might decrease the support for the technology in this study.

8.4 Further research

Many suggestions for further research have already been made throughout the discussion and limitations; however, there are four points that deserve additional consideration.

8.4.1 Perceptions of different samples and groups of stakeholders

The methodological limitations of the samples in each empirical phase of the research are well documented throughout the thesis and in the above section. This study represents an initial study into public perceptions of ammonia and future research should continue to build on this by focusing on additional groups and ensuring representative samples where possible. For example, in *Chapter 5* it was suggested to explore further views from experts from a different background (e.g., perhaps technologies involving green hydrogen, biofuels, methanol, CCS etc.). Additionally, further research could involve people currently working with ammonia as a chemical or even green ammonia as a fertilizer, which companies like Yara are currently producing (Yara International, 2021). When involving people from different backgrounds, risk perception might be different, as well as the perception of the role of laypeople. Most of the interviewees in this research were from companies that are developing green ammonia technologies as a fuel that are not in a commercial stage yet. However, green ammonia as a fertiliser has been in the market for years, which might bring a different standpoint from "experts" to the research if a perspective from these technologies is taken into account.

Similarly, there may be communities and groups in the population which will become particularly relevant to study in the future as the technology matures and specific applications are developed. For example, in the case of use of ammonia in the maritime industries, communities near storage facilities and harbours where the fuel is frequently transported and used may be of particular interest.

8.4.2 Psychological factors explaining public acceptability and acceptance of green ammonia

Based on a review of broad frameworks for understanding technology acceptance and risk perceptions (Chapter 3), this thesis has focused on risk and benefit perceptions, affective responses and trust as important variables explaining people's responses to green ammonia (including climate change). All of these factors were examined in some detail and found to be important for explaining initial support or opposition towards green ammonia. For example, in the case of Mexico, our findings help to elucidate the challenges of implementing emerging technologies in the country, due to lack of trust in the government, but also accentuate the debate likely to arise around water intensity.

There are, however, a number of other psychological and cultural factors which are likely to be important for understanding public perceptions and acceptability of green ammonia. For example, Huijts et al's (2012) model also suggests that prior knowledge, personal and social norms as well as justice beliefs are likely to be important. Similarly, the research on risk perception models indicates that there may be a number of cultural worldviews that could potentially explain differences within and between countries. One aspect that this relates to is religion.

This study highlights the importance of doing in-depth research on public perceptions of green ammonia with a national representative sample. In the case of Mexico, our findings help to elucidate the challenges of implementing emerging technologies in the country, due to lack of trust in the government, but also accentuate the debate likely to arise around water intensity. Additional research should be carried out to analyse trust on an independent regulator.

Throughout this research the focus has been to develop the first public perception study in the area of green ammonia focused on two groups, *experts* and *general public*. However, we suggest further research to involve additional groups. For example, in *Chapter 5* it was suggested to explore further views from experts from a different background (e.g. perhaps technologies involving green hydrogen, biofuels, methanol, CCS etc.). Additionally, further research could involve people currently working with ammonia as a chemical or even green ammonia as a fertilizer, which companies like Yara are currently producing (Yara International, 2021).

During the focus groups, one hour was established to present all the information and obtain responses from participants, we acknowledge that this might have been not enough time to obtain in-depth perceptions of the technology. However, the aim was to obtain participation from a wide variety of backgrounds and not overburden participants, allowing us to gather insights into people's initial responses. Future research involving qualitative tools and presenting information to participants about green ammonia, could expand the time and obtain in-depth responses. Mexico holds the second largest catholic population in the world (Clarke, 2016) and studies have shown that religion has a great impact on the population. According to the Mexican newspaper *El Universal* citing information from the National Council of Science and Technology, 72.24% of the Mexican population beliefs more in religion and magic than in science (El Universal, 2022) (Santillan, 2017). For example, a study in Costa Rica included a question about God regarding CC knowledge: "Climate change happens through the will of God". Results showed that 75.6% of the respondents felt that CC is influenced by the will of God. Therefore, we recommend that further research includes a question regarding religious thoughts on CC and trust to develop the technology, e.g., trust in religious leaders as stakeholders to develop the technology (Vignola et al., 2013).

8.4.3 Other forms of social acceptance: from the national to the local

At the beginning of chapter 3, a number of theoretical frameworks for understanding public acceptance of low-carbon energy technologies are reviewed. This thesis examines public acceptance at the national/socio-political level given that green ammonia technologies are not yet deployable. However, as the technology matures and applications become more specific and implemented at specific locations, it will become important to examine public acceptance at, what Upham et al., (2015) calls, meso and micro levels (or community acceptance as it is called in other frameworks). We know from these models and previous research that at a community level, when technologies are situated in specific places, other factors become important for understanding public acceptance, including for example, aesthetics, the 'fit' of the technology in the landscape, the distribution of risks and benefits of the technology etc (Boudet, 2019). Issues to do with the process of implementing technologies will also become more salient, for example procedural justice (e.g., transparency of decision-making, having a voice in the process), and trust in specific developers and owners of the technology (Boudet, 2019, Wuestenhagen et al, 2007; Huijts et al., 2012). Therefore, it is vital that future research goes beyond the socio-political level as discussed in this thesis to also consider these factors relevant for the community level.

8.4.4 Information provision and framing

The current research opted to examine initial responses to green ammonia in the context of climate change because the technology is being developed as a solution to climate change. The expert interviews also revealed that the low-carbon properties of green ammonia are the main, and perhaps only, driver for developing the technology. Nonetheless, throughout the thesis it has been acknowledged that different ways of framing technologies can affect public perceptions and acceptability (Whitmarsh et al., 2019). Indeed, the findings show that despite some negative affective responses and risk perceptions associated with ammonia as a chemical, green ammonia as a technology is viewed positively in both Mexico and UK. The 'idea' of green ammonia is therefore one that attracts positive reactions and support. This is in line with other research that shows that climate change and sustainability framings can have positive effects on how technologies are perceived (Jones et al., 2021) (Hayashi et al., 2016).

Another important aspect to consider is information provision and the pseudo-attitudes (Upham et al., 2015). In the current research, we focused on initial impressions, affective reactions and support for green ammonia. These do not represent fully formed or even informed preferences, but rather provide an indication of the initial reactions and emotional responses that are likely to influence a preference formation process. It is likely that people's actual preferences and acceptance will depend on a number of factors. For example, people in the focus groups wanted to know more about how the technology would be used, how much water it would use, who would develop it, and how it compares to other technologies.

Therefore, future research should examine different framing and information-provision scenarios to gain a more in-depth understanding of potential preferences across these. Use of different methodological tools to examine a potential preference construction process for green ammonia may also be useful, for example the information-choice questionnaire method has been used successfully with CCS (de Best-Waldhober et al., 2009), where participants are given extensive information on the technology across a number of dimensions (e.g., risks, costs, technology readiness) and asked to evaluate the information as well as provide their preferences for different CCS applications. This also enables a more in-depth analysis of people's responses to different pieces of information about the technology and provides an opportunity for participants to developed informed opinions on the topic. Other studies have examined different framings of low-carbon technologies, which emphasise particular aspects of a technology or attempt to stay neutral, e.g. (Ferguson & Ashworth, 2021) (Pidgeon et al., 2012). This would provide important context for future communication about green ammonia.

In summary, from the literature review and findings of this thesis, different framings and information provisions scenarios are applicable to the green ammonia context and should be investigated as to their effect on public preferences in the future. These include but are not limited to:

- Comparing ammonia to hydrogen as an energy vector and storage option
- Comparing alternative storage technologies to green ammonia
- Different applications of the technology and different scenarios on how the technology is implemented (e.g., information about where water used in the process is taken from)
- Neutral vs climate change framings of the technology
- Different levels of information provision about risks and benefits

Apart from religion and trust in religious leaders, additional social aspects could also be included in future research concerning green ammonia. Analysing further the role of trust must be considered by including independent regulators as one of the options. Additionally, taking into account the Technology Acceptance Framework from Huijts et. al. experience with the technology could be an important factor influencing acceptance, further research could consider comparing responses from people familiarised with the uses of ammonia as a chemical and their perception if the chemical is used as an energy vector.

8.5 Recommendations for stakeholders and developers of green ammonia

The research presented in this thesis represents a first exploration of public perceptions of green ammonia. In *Chapter 2,* it was argued that understanding public perspectives and responses this early in the development of an emergent technology is an important aspect for responsible innovation and providing insights for those developing green ammonia. The below summarises key findings and recommendations as they have emerged from the current research with a view to inform the future technological development and risk communication.

- Although ammonia is not used in energy applications today, it is increasingly likely that ammonia will be one of the renewable energy vectors. This should be perceived as an advantage to start considering the public at early stages before the full deployment of the technology. The research in this thesis should be considered as a starting point for incorporating public engagement into the technology development process. Future research as outlined in the previous section should be funded as part of this work.
- Context is fundamental to understand public perceptions of risks and benefits for green ammonia technologies. The country where the technology is developed will play an essential role on how people perceive the technology. It is recommended that technological applications are developed in a way that is sensitive to issues relevant in a particular country. This research, for example, suggests that water scarcity is particularly salient in Mexico and that trust is currently a barrier towards its development.
- Regulation is therefore key; how the technology will be regulated by stakeholders will be key for its development as trust is an important factor not only for the general public but also for experts. Ways of improving trust should be explored by policy makers, industry and academia involved in developing green ammonia.
- Developing a comprehensive understanding of public risk and benefit perceptions is important for developing ethical and robust governance structures for green ammonia technologies in the future.
- Communication approaches should recognise, as this study illustrates, that experts and laypeople often have different perspectives about the risks and benefits of green ammonia. Findings in this study suggests that British respondents view NOx emissions as concerning, and Mexican respondents prioritise water intensity of the technology.
- Green ammonia is an emerging technology, this should be first acknowledged when communicating the benefits of the technology. Based on the results and literature review presented in the current study we can conclude that how green ammonia is presented and who is delivering it, will play an important role for its acceptance. This study suggests that highlighting its role in addressing climate change was positively received by the general public and therefore this kind of framing is likely to lead to support of the technology.

8.6 Conclusions

It is a reality that green ammonia interest and investment is increasing worldwide; countries are adopting this technology as a measure to tackle greenhouse gas emissions. As renewable energy technologies keep growing, the need to store and transport excess energy follows the same path, transforming green ammonia into the essential mean to store and carry energy. Even though several barriers have to be overcome in the next coming years from a technical perspective, acceptance from the public will also be a key aspect for full implementation.

This is an initial exploration of public perceptions of the technology. It therefore is a first attempt at understanding what benefits, risk and concerns people perceive about the technology and how this might differ to experts in the technical aspects of green ammonia. The thesis has explored perceptions of the technology from experts and laypeople, obtaining positive outcomes from both groups. Nevertheless, we need to remember that positive responses are also highly dependent on several factors, such as information-provision, framing, perception of risks and benefits, trust, affect, cultural context among others. Trust appears to be a particularly critical factor - a lack of trust in stakeholders to develop and regulate the technology may increase the public's perception of risks and, therefore, decrease the recognition of the benefits, even to a point where the purpose of technology is no longer acknowledged (Bronfman et al., 2012).

This research highlights the importance of involving the public at early stages of the development of the technology. It is fundamental to understand people's beliefs at any stage of a technological process considering the impact that their opinion will have during deployment. Mainly, with upstream technologies, like ammonia, where its effectiveness, cost and risks are uncertain, public perception studies will point out ethical and value issues people consider important.

Several suggestions for further research have been proposed through the thesis where it has been advised that further research continues with this line of research looking for a representative sample in Mexico and the UK, involving additional groups comparing responses from people familiarised with the uses of ammonia as a chemical and their perception if the chemical is used as an energy vector (e.g., people in contact with ammonia as a fertiliser). Explore different framings (e.g., with and without CC framing), comparing ammonia to hydrogen or other alternative storage options, analysing the impact of additional social and cultural factors (e.g., religion or independent regulators) and continue to involve developing nations in this kind of research.

Technological responsibility also requires a new public standard of accountability, "to establish the needs of the future within the present"— (Groves, 2006). The next step of innovation is not only to consider technical aspects but to recognise the importance of a joint effort between key players and formulate an ethics of care for the future, where a comprehensive vision is in line with ethical reasoning, taking into account both public and stakeholders. This vision should be taken further and be taken into account for risk communication in the field of green ammonia. This study has provided important initial insights in this regard, providing recommendation for further research, development of, and communication about, green ammonia as an emerging technology.

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APPENDICES

The appendix contains the materials of the empirical research phases, more detailed topline results of the surveys, and supplementary information regarding analyses presented in the thesis.

Appendix A - Chapter 5

Appendix A.1 – Questionnaire: Experts

QUESTIONS
EXPERTS INVOLVED WITH AMMONIA

Aim: Understand why ammonia technologies are being developed
Research questions:

- Why these ammonia-based technologies have been developed?
- What are the risks and benefits associated with ammonia?
- To what extent have public perspectives already been considered in the development of ammonia-based energy systems?

General questions

Demographic questions

- Name
- Age
- Gender

Introductory questions

Just to start, tell me about yourself and the technology you are working on.

- Profession
- Background details
- Explanation of the technology they are working on with ammonia
  - *Is it for energy production, storage or distribution?*

Ammonia questions

Reasons for developing ammonia-based energy technologies

- **Q.1** Why are you developing the technology specifically with ammonia?
- **Q.2** What do you think about ammonia as an energy vector, for power distribution and storage?
- **Q.3** Why these technologies have been developed?
  - *Is there another reason?*

- **Q.4** What are the main advantages of working with ammonia?
  - *Is there another aspect you consider as an advantage?*
- **Q.5** What are the main disadvantages of working with ammonia?
  - *Is there another aspect you consider as a disadvantage?*
  - *Do you consider smell an advantage or disadvantage?*

Risks and Benefits associated with ammonia use

- **Q.6** What would it be your main concern if this technology is implemented?
  - *Technical level*

- *Social level*
- *Economical level*

- **Q.7** Which benefits you associate with this technology?
    - *Technical level*
    - *Social level*
    - *Economical level*
- **Q.8** What do you think the main risks are or will be once it gets to a commercial stage?
    - *Technical level*
    - *Social level*
    - *Economical level*

The perceived role of laypeople in developing these technologies

- **Q.9** Do you think is important to understand how people perceive ammonia?
- **Q.10** Do you think public perceptions are important in the development of ammonia-based technologies?
- **Q.11** At what stage of the technology?
    - *Early/late stage*
- **Q.12** How do you think general public will respond to ammonia-based systems?
    - *Does people react someway when you tell them you are working with ammonia? Are they positive or negative comments?*
    - *Would you think they will fully understand the technology? Won't they be worried about maybe costs? Security?*

- **Q.13** What do you think public will be more interested in, ammonia for energy storage/distribution or for energy production? Why?
- **Q.14** In your current work with ammonia, are you considering people's perceptions?

Q.14.5 *If they don't mention smell*

- *Would you consider the smell an advantage or disadvantage?*

Perceptions and expectations about future costs of these technologies

- **Q.15** How affordable do you think this technology will be once it gets to a commercial point?
    - *How long you think it will take to get to a commercial point?*
    - *Maybe in comparison with other fuels?*
- **Q.16** Do you consider cost to be an advantage or disadvantage for ammonia-based technologies?

Perceptions about renewable energy as energy production technologies

Q.17 What are your perceptions about renewable energies and storing excess energy as ammonia?

General Prompts

- *In question_ you mentioned _ can you tell me more about it…*
- *Why do you think is/is not important*
- *Could you tell me more about …*
- *What have you heard*
- *Can you give me some more detail about that*

Appendix A.2 – NVIVO Coding

NVIVO CODING

- **Reasons for developing ammonia-based energy technologies**
  - Perception of ammonia-based systems
    - Energy distribution
    - Energy storage
    - Energy vector
  - Advantages
    - Knowledge
    - Storage
    - Carbon-free
    - Business Opportunity
    - Distribution
    - Combustion
    - Safety
    - Versatility
  - Disadvantages
    - Toxicity
    - NOx
    - Public Perception
    - Corrosion
    - Smell
- **Risks and benefits associated with ammonia use**
  - Risks
    - Market
    - Safety
    - Acceptance
    - Politics
  - Benefits
    - CO2 free
    - Energy Independence
    - Cost-effective
  - Concerns
    - Cost
    - High demand
    - Public Perception
    - NOx
    - Safety
- **The perceived role of laypeople in developing these technologies with ammonia**
  - Importance of understanding ammonia perception
  - Smell
  - Stage
    - Early Stage
    - Middle Stage
    - Final Stage
    - Once is commercial
- **Perceptions and expectations about future costs of these technologies**
  - Expensive
  - Cheap
  - Advantage

    - Disadvantage

- **Perceptions about renewable energy as energy production technologies**
    - Positive
    - Negative
    - Mixed
    - Neutral
- **Comparisons**
    - Comparison with other fuels
        - Fossil Fuels
        - Hydrogen
        - Nuclear
    - Comparisons with history
        - Belgium
        - Pakistan

Appendix B – Chapter 6

Appendix B.1 – Questionnaire: Focus Groups

Designed Questionnaire

Introduction to climate change
Explanation about climate change:

"Thank you for all your information, what I want to talk about today is ammonia being used as a carbon-free fuel and its capacity to store energy (like a battery), which I'm going to explain in detail in a couple of minutes. However, the main reason why we are talking about this and presenting this new concept, is because of climate change"

Q.3

- Is anyone familiar with the concept "climate change"?
- Yes, what have you heard?

[Slide 2: Explanation of climate change]
Q.4

- Are you concerned about climate change (choose a participant)?
- What do you know about what causes climate change? (see if they talk about energy and fossil fuels)

Fuels
[Slide 3: List of fuels]
Q.5

- Here is a list of some fuels, have you heard anything about any of these fuels?
    - Which ones you think are low carbon? (do you know what low carbon is?)
- Which ones do you think they are contribution to climate change?

[Slide 4: Impact of fuels in climate change]

“As you can see, fossil fuels play a main role in climate change, that is why the need for a carbon-free fuel. Currently, the only two fuels with no carbon in them are hydrogen and ammonia”
[Slide 4: Present ammonia-hydrogen as clean fuels]
[Slide 6: Current production of ammonia]
[Slide 7: Green-ammonia infographic]

Green Ammonia
Q.6

- What do you think about this concept of “green-ammonia”?
- Do you see any disadvantages or risks in using this technology?
- Advantages/benefits?

“One criticism about using ammonia as a fuel is that if it is not use properly, then it can contribute as well to climate change”

Q.7

- Would you be worried about this? Why?
- What is your main concern about this technology?

Risks and Benefits
[Slide 8: Table with risks and benefits]

Q.8

- Are there any risks you are worried about the most?
- What do you think is the most attractive advantage?

Ammonia in Mexico
[Slide 9: Reasons to develop this technology in Mexico]

“Currently Mexico has high revenues in agriculture and depends on ammonia as a fertiliser. Therefore, Mexico has an existing infrastructure for the transportation and storage of ammonia gas, as well as local knowledge”

Q.9

- What do you think about this information?
- Is it attractive for you to know that ammonia is being used all around Mexico and this might help to boost a green ammonia technology?

Q.10

- Is there something additional you like/dislike about the technology?

Trust
Note: Government/corruption might come up as one of the answers due to current change of government.

Q.11

- If we use this technology in Mexico, would you trust the government to regulate it? Or would you trust the industry?

[Slide 9: Most attractive uses for the technology: maritime industry, for energy storage]
Help cutting the shipping sector’s greenhouse gas emissions in half by 2050

Q.12
If I tell you, that one of the most attractive uses of ammonia is for energy storage for the maritime industry, what would you say?

Closing
"Is there anything else you like to contribute or say in relation to what we discussed today?"

Thank you!

If costs come up in the conversation try to explore the topic:

- "any new technology is quite expensive, but we don't know exactly yet how much it will be... would this be something you'll be concerned about?"
- Would you just want to make your bills as cheap as possible or would you be willing to pay a bit more to have a green energy?"

Appendix B.2 – Coding: Focus Groups

CODING

First Associations
- Risks
- Benefits

Climate Change
- Familiarity with climate change
- Causes
- How concerned

Fuels
- Contribute to climate change
- Unknown

Green Ammonia
- First Impressions
- Advantages
- Concerns
- Questions asked

After presenting the table
- Risk
- Benefits

Ammonia in Mexico
Costs
Trust
Other

Coding	Sub-codes	Description
Nothing/I don’t know		Don’t know, unsure, NA, nothing, none/ have no idea/nothing comes to mind
First Associations	I have heard the word	Familiarity but not sure. It sounds familiar/I think I’ve used it somewhere.
	Chemical	Any mention of ammonia chemical properties. A chemical/ nitrogen/hydrogen/NH3/NH4
	Cleaning Product	Any mention as a product for cleaning/bleach/disinfectant
	Beauty products	Any mention of beauty products. Hair dye/makeup
	Smell	Responses about the smell. Penetrating smell/smells horrible /unpleasant
	Other products	Mention of any other products containing ammonia. Bombs/explosives.
Climate Change - Familiarity	Yes	Responses confirming participants have heard about climate change and its impact. I have heard we don’t have a lot of time left.
	No	Any response indicating participants have never heard about CC. I don’t know what CC. is/I have heard it but I am not sure.
Climate Change - Concern	Very concerned	Responses indicating a high concern about CC. I am very worried/ we need to act now.
	Somewhat concerned	Any mention of not being too concerned about CC. I don’t worry too much/I’m not too concerned/I don’t think it’s too important.
	Not concerned at all	
	Sceptical	I don’t believe CC is happening / It is a natural process
Fuels	Contribute to CC	Responses indication fuels contribute to CC.
	Some fuels contribute to CC	Responses only pointing out some fuels contributing to CC.
	Fuels don’t contribute to CC	Any mention that none of the fuels presented contribute to CC.
Green Ammonia	Need more information	Any mention of needing more information to decide. Queries about what it is and how it works
	Positive	Open concepts expressing positive feelings. Sounds promising/looks like a good idea /interesting/great idea/amazing/impressive/beneficial
	Negative	Open concepts expressing negative feelings 2.1 concepts/terrible/bad
	Sceptical	I don’t believe it. Not sure it can work. 7.5 It will end up being like any other technology
Advantages	Environment	Good option for the environment/good green 8.9 fuel/less pollution
	Positive	Open concepts expressing positive feelings. Sounds promising/looks like a good idea /interesting/great idea/amazing/impressive/beneficial.
	Other advantages	Mention of other advantages
Concerns	Safety	Any mention of the safety behind the technology
	water	Any reference to water, water quality, shortages
	Smell	Responses about the smell/ penetrating smell or odour
	Cost	Being expensive
	Other concerns	Mention of other concerns. Social inequality.
Other	Complex/confusing	Any reference to being confused, puzzled, too complicated
	Alternatives	Mentions of other solutions. Better invest in other technologies/other technologies are better
Ammo	Legislation	Politics/government/laws/control/corruption

	Positive	Any positive comment regarding ammonia in Mexico.
	Not possible	Any mention of being possible in other countries but not in Mexico.
Trust	Government	Any mention of trust in the government to develop the technology
	Industry	Any mention of trust in the industry to develop the technology
	Both	Any mention of trust in the government and industry to develop the technology
	None	Any comment mentioning total distrust. I don't trust anyone
	Other	Mention of other institution or person. I trust environmental agencies.
Other/Misc		Responses that don't make sense, reword question, do not answer question.

Appendix B.3 – Participants' Information

PARTICIPANT	NAME	Age	Gender	OCUPATION	EDUCATION LEVEL
1.1	Beatriz	66	F	Unemployed	High School
1.2	Ramiro	29	M	Receptionist	High School
1.3	Sebastian	26	M	Actor	High School
1.4	Giselle	50	F	Teacher	University
1.5	Natalia	30	F	Accountant	University
1.6	Ricardo	23	M	Tax consultant	University
1.7	Irma	22	F	Teacher	University
1.8	Anonymous	74	F	Unemployed	High School
2.1	René	30	M	Advertising Editor	High School
2.2	Andrea	24	F	Student	High School
2.3	Armando	29	M	Graphic Designer	University
2.4	Erik	28	M	Web Programmer	BTEC
2.5	Luis	36	M	Art Director	University
2.6	Roberto	61	M	Publicist	University
2.7	Nadya	33	F	Publicist	High School
2.8	Javier	33	M	Web Programmer	University
2.9	Enrique	24	M	Publicist	University
3.1	Ana	29	F	Unemployed	University
3.2	Ernesto	27	M	Unemployed	High School
3.3	Camila	58	F	Owner of a food business	University
3.4	Gabriela	54	M	Household employee	Primary School
3.5	Roxana	42	F	Household employee	Secondary School
3.6	Dom	32	M	Contador	University
3.7	Deborah	34	F	Unemployed	University
3.8	Edgar	23	M	Driver	University
3.9	Julia	23	F	Student	High School
3.10	Lourdes	52	F	Household employee	Secondary School
4.1	Carla	29	F	PR agency	University
4.2	Armando	28	M	Graphic Designer	University
4.3	Regina	29	F	PR agency	University
4.4	María	29	F	Publicist	Master's Degree
4.5	Daniela	28	F	Publicist	University
4.6	Julian	27	M	PR agency	University
5.1	Christian	29	M	Driver	College
5.2	Antonio	47	M	Production manager	University
5.3	Emilia	18	F	Student	College
5.4	Gerardo	51	M	Driver	Secondary School

5.5	Marisol	55	F	Domestic Employee	Secondary School
5.6	Lino	50	M	Accountant	University
5.7	Jaime	42	M	Manager	High School
5.8	Mauricio	58	M	Tax Consultant	Master’s Degree

Appendix B.4 – Education level in Mexico

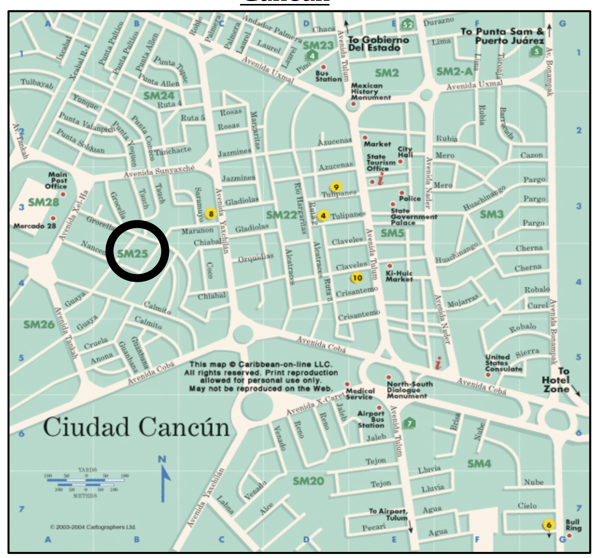
Education Level	Duration	Age
Primary School	6 years	From 6-12 years old
Secondary School	3 years	From 12 – 15 years old
High School	3 years	From 15- 18 years old
BTEC (Technical course)	3 years	From 18-20 years old
University (Bachelor’s degree)	4-5 years	18- 22

Appendix B.5 – Zone division in Mexico City and Cancun

○ Location of venues for the focus groups

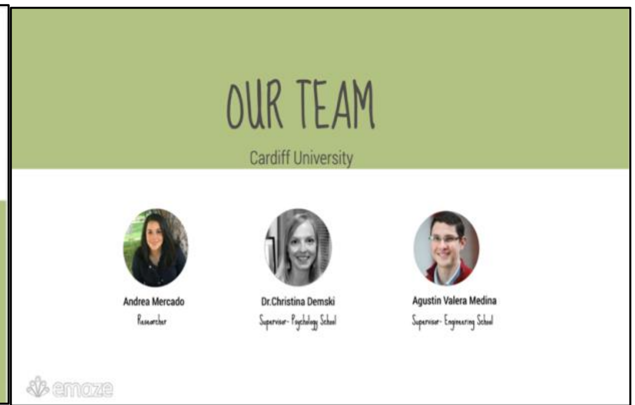
Mexico City

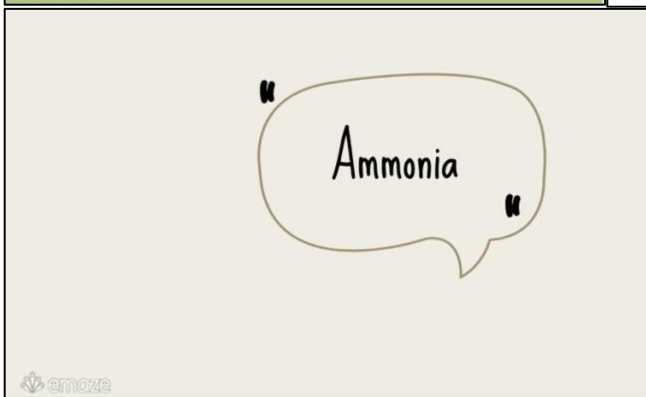
Cancun



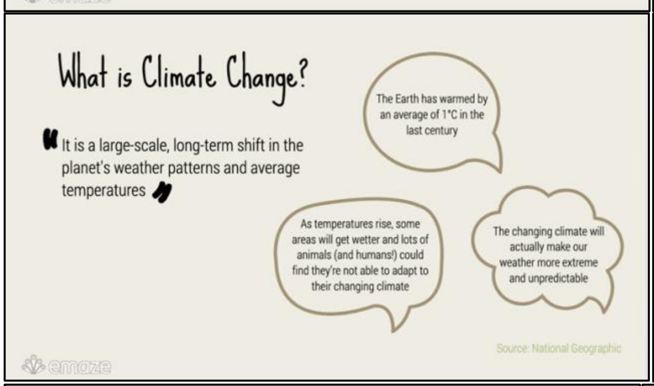
Appendix B.6 Presentation Slides

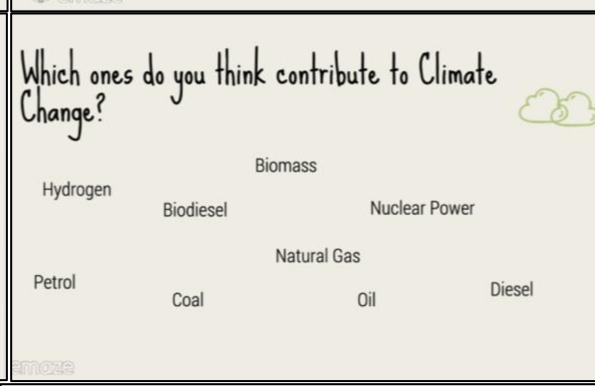

Welcome

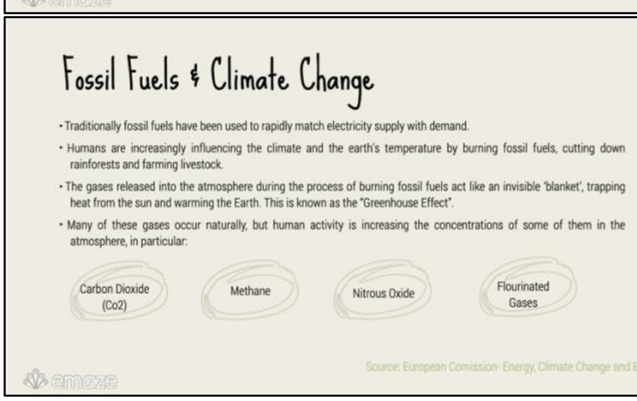

OUR TEAM
Cardiff University
Andrea Mercado
Researcher
Dr.Christina Demski
Supervisor- Psychology School
Agustin Valera Medina
Supervisor- Engineering School

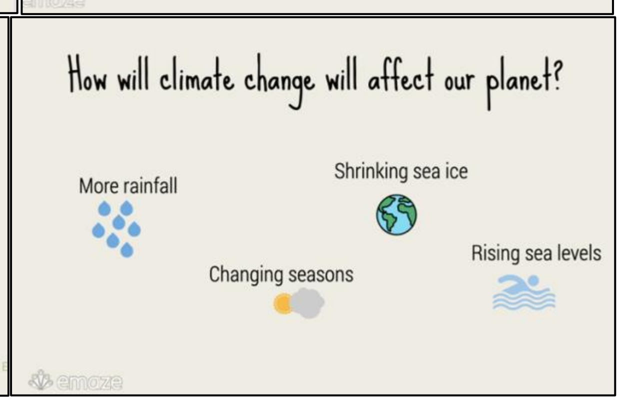

Ammonia

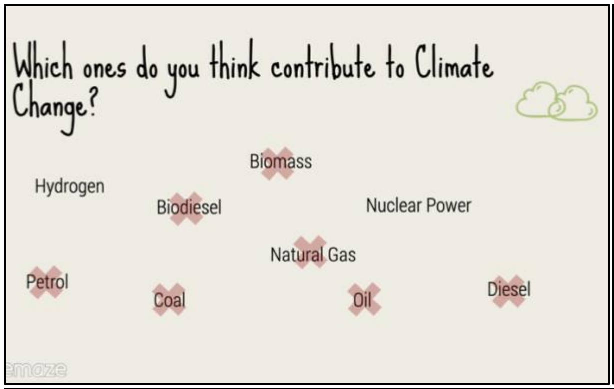

Climate Change

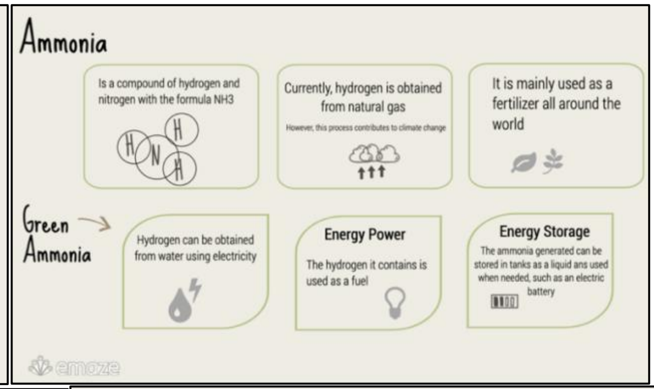

What is Climate Change?
It is a large-scale, long-term shift in the planet's weather patterns and average temperatures
The Earth has warmed by an average of 1°C in the last century
As temperatures rise, some areas will get wetter and lots of animals (and humans!) could find they're not able to adapt to their changing climate
The changing climate will actually make our weather more extreme and unpredictable
Source: National Geographic

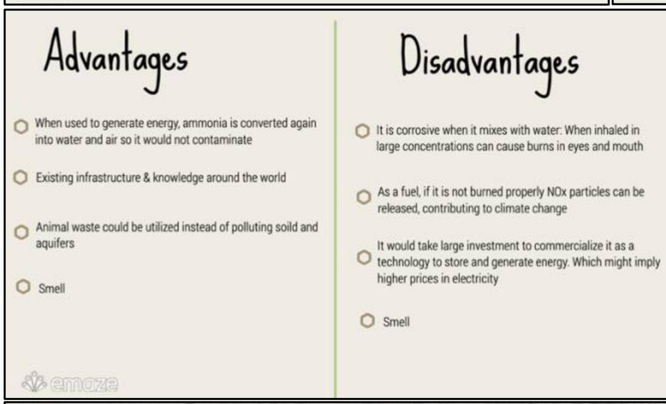

Which ones do you think contribute to Climate Change?
Biomass
Hydrogen
Biodiesel
Nuclear Power
Natural Gas
Petrol
Coal
Oil
Diesel

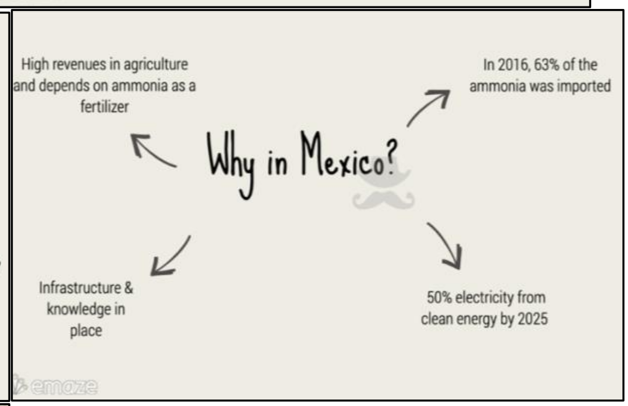

Fossil Fuels & Climate Change
• Traditionally fossil fuels have been used to rapidly match electricity supply with demand.
• Humans are increasingly influencing the climate and the earth's temperature by burning fossil fuels, cutting down rainforests and farming livestock.
• The gases released into the atmosphere during the process of burning fossil fuels act like an invisible 'blanket', trapping heat from the sun and warming the Earth. This is known as the "Greenhouse Effect".
• Many of these gases occur naturally, but human activity is increasing the concentrations of some of them in the atmosphere, in particular:
Carbon Dioxide (Co2)
Methane
Nitrous Oxide
Flourinated Gases
Source: European Comission- Energy, Climate Change and E


How will climate change will affect our planet?
More rainfall
Shrinking sea ice
Changing seasons
Rising sea levels









Appendix C - Chapter 7

Appendix C.1 – Recruitment information shared with participants

Social media texts

Hi everyone!
I need your help for the last phase of my PhD
(you need to be over 18 and living in the UK)
As part of my research, I'm conducting a survey about climate change and new energy technologies. It will take you only 15 minutes to complete and all responses are completely anonymous.
Link: https://cardiffunipsych.eu.qualtrics.com/.../SV...

I am so grateful for your participation!
Please share this survey with anyone else living in the UK who might want to take part!

¡Hola!
¡Necesito su ayuda para la última parte de mi doctorado! Únicamente necesitan ser mayores de 18 años y vivir en México
Como parte de mi investigación, en la Universidad de Cardiff (Reino Unido), estamos realizando un estudio para conocer la opinión de los mexicanos acerca del calentamiento global y nuevas tecnologías energéticas. Queremos pedirte sólo 15 minutos de tu tiempo para contestar algunas preguntas de forma anónima.
Link: https://cardiffunipsych.eu.qualtrics.com/.../SV...
¡Compártela con amigos y familiares que vivan en México!

Generic Email text

Hello,

My name is Andrea Guati Rojo, PhD researcher at Cardiff University.

We are conducting at **Cardiff University** an online survey about **public perception of climate change** and **ammonia as an energy vector.**

It takes just 15 minutes to complete and is completely anonymous (it will be impossible to trace any answer back to you individually)

https://cardiffunipsych.eu.qualtrics.com/jfe/form/SV_0CaSsbbLDRd83zL

Please share the link with anyone else who might be able to help, they just have to be over 18 and living in the UK to take part!

Thanks a lot for your help!

Andrea M. Guati Rojo
PhD Researcher

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70 Park Place, Cardiff, CF10 3AT, UK
Tel: +44 (0)29 2087 6692
Research profile: Andrea Guati Rojo
Linkedin: Andrea Guati Rojo

Appendix C.1.1 – Surveys: Complete Questionnaire in English

Thank you for your participation in this anonymous questionnaire.

Only an *adult (+18)* should complete this questionnaire.

It consists of a series of questions about climate change and new energy technologies. Please tick the box that best describes your opinion for each question. Please answer questions in order.

There are 31 questions in total and should take around 20 min to complete. It is entirely voluntary so you can withdraw from the study at any time without giving a reason.

No special knowledge is required. There are no right or wrong answers! All points of views are welcome! Your views count!

The research is completely independent and is not linked to any industry, government or interest group.

The information you provide here will be held totally anonymously, so that it is impossible to trace this information back to you individually. This information may be retained indefinitely or published.

Please direct any questions you have to the researcher using the contact details at the end of the questionnaire

If you consent to participate in the study, please proceed by pressing the ‘continue’ button below. *Important: please do not use your browser 'back' button as this will result in your data being lost.*

DEMOGRAPHICS

Gender

- Female
- Male
- Other
- Prefer not to say

Age

- 18-24
- 25-34
- 35-44
- 45-54
- 55-64
- 65+

Level of Education

- Less than high school
- High school graduate
- 2-year degree
- 4-year degree
- Professional degree
- Doctorate
- Other

Working Status

- Working - Full time (30+ hrs)
- Part-time (9-29 hrs)
- Unemployed
- Not working - retired
- Looking after house/children
- Invalid/disabled
- Student
- Other

In politics people sometimes talk of "left" and "right". Using a scale from 0 to 10, where 0 means the left and 10 means the right, where would you place yourself on this scale?

			Left						**Right**		
	0	1	2	3	4	5	6	7	8	9	10

Regional Location:
What state of Mexico (UK) do you live in?

____

- ○ I prefer not to say

FIRST ASSOSIATIONS

What are the first thoughts or images that come to mind when you hear the term 'ammonia'

(1) ____

(2) ____

PERCEPTIONS OF CLIMATE CHANGE

This set of questions will ask you about your thoughts and opinions on climate change (sometimes referred to as global warming).

You may have heard the idea that the world's climate is changing due to increases in temperature over the past 100 years. What is your personal opinion on this? Do you think the world's climate is changing?

- Definitely changing
- Probably changing
- Probably not changing
- Definitely not changing
- Don't know

How worried, if at all, are you about climate change?

- Not at all worried
- Not very worried
- Fairly worried
- Very worried
- Extremely worried

Do you think that climate change is caused by natural processes, human activity, or both?

- Entirely by natural processes
- Mainly by natural processes
- About equally by natural processes and human activity
- Mainly by human activity
- Entirely by human activity
- I don't think climate change is happening
- Don't know

How serious of a threat, if at all, is climate change to each of the following?

	Not at all serious	**Not very serious**	**Fairly serious**	**Very serious**	**Extremely serious**
You and your family					
The UK as a whole					
People in developing countries					

How much do you think climate change will harm you personally?

- A great deal
- A lot
- A moderate amount
- A little
- None at all

Which one, if any, of these do you feel should be mainly responsible for taking action against climate change?

- Industry
- National Government
- Society
- Local Government
- Individuals and their families
- Environmental groups
- The international community
- None of these

In the next 3 months, how many times do you plan to:

	None	**1-4 times**	**5-8 times**	**9- 12 times**	**12+**
Turn off lights you're not using					
Drive economically (e.g., braking or accelerating gently)					
Walk, cycle or take public transport for short journeys (i.e., trips of less than 3 miles)					
Use an alternative to travelling (e.g., shopping online)					
Share a car journey with someone else					
Cut down on the amount you fly					
Buy environmentally-friendly products					
Eat food which is organic, locally-grown or in season					
Avoid eating meat					
Buy products with less packaging					
Recycle					
Reuse or repair items instead of throwing them away					
Compost your kitchen waste					
Save water by taking shorter showers					
Turn off the tap while you brush your teeth					

A study published in 2017 by the Universities of Lund and British Columbia suggested that the single most effective measure an individual in the developed world could take to cut their carbon emissions over the long term could be to have one fewer child.

How do you feel about limiting the number of children in the future per family as a measure to tackle climate change?

- Strongly agree
- Agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Disagree
- Strongly disagree

ENERGY SOURCES

To what extent do you believe the following energy fuels/technologies contribute to Climate Change?

	It contributes	It does not contribute	I've never heard of it
Biodiesel			
Biomass			
Coal			
Diesel			
Gasoline			
Hydrogen			
Natural Gas			
LP Gas			
Nuclear			
Biofuels			
Hydroelectric Power			
Wind Power			
Solar Panels			
Tidal power			

To what extent you support or oppose the use of…

	Support	Oppose	I've never heard of it
Biodiesel			
Biomass			
Coal			
Diesel			
Gasoline			
Hydrogen			
Natural Gas			
LP Gas			
Nuclear			
Biofuels			
Hydroelectric Power			
Wind Power			
Solar Panels			
Tidal power			

KNOWLEDGE ABOUT CC

To what extent do you think the following statements are correct or incorrect…

	Correct	**Incorrect**	**Don't know**
- Burning oil produces CO_2			
- Nuclear power plants emit CO2 during operation.			
- The global CO2 concentration in the atmosphere has increased during the past 250 years			
- The last century's global increase in temperature was the largest during the past 1,000 years			

For the next decades, the majority of climate scientists expect…

…an increase in extreme events, such as droughts, floods and storms.

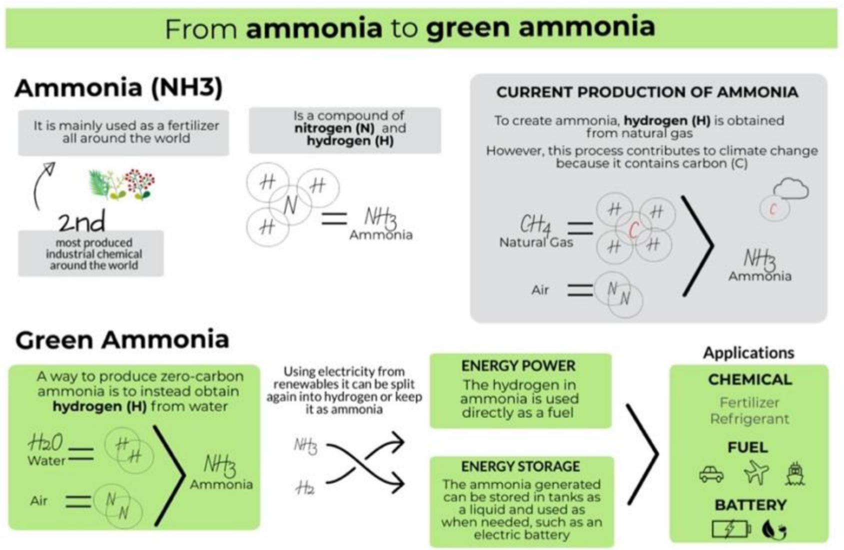
…the climate to change evenly all over the world.

GREEN AMMONIA

Please read the following information carefully:

Traditionally fossil fuels have been used to rapidly match electricity supply with demand. Humans are increasingly influencing the climate and the earth's temperature by burning fossil fuels, cutting down rainforests and farming livestock. This is why the need for a carbon-free fuel. Currently, few fuels exist with no carbon (i.e. hydrazine, hydrogen sulphide, ammonium nitrate, etc.). Amongst these, hydrogen and ammonia are the simplest and most promising.

Here we are going to present a new alternative to produce a carbon-free fuel:



Please tell us what thoughts or images came to mind when reading this information about green ammonia?

In general, how do you feel about green ammonia?

- Extremely positive
- Moderately positive
- Slightly positive
- Neither positive nor negative
- Slightly negative
- Moderately negative
- Extremely negative

RISKS AND BENEFITS

The use of ammonia can have both **risks** and **benefits**:

To what extent are you worried about the following…

	Not at all worried	Not very worried	Somewhat worried	Very worried	Extremely worried
Ammonia is a toxic gas that when inhaled in large concentrations can cause burns in eyes and mouth					
Ammonia technology to store and generate energy would need a large investment to commercialize, this might imply higher prices in electricity					
Ammonia has a very unpleasant smell					
Ammonia technology is water intensive so it would need to be developed in areas with easy access to water					

On the whole, how acceptable or unacceptable are the risks of green ammonia to you?

- Very acceptable
- Acceptable
- Neither acceptable nor unacceptable
- Unacceptable
- Very unacceptable

Do you have any other concerns about ammonia?

____

To what extent are you positive about the following…

	Not at all positive	Not very positive	Somewhat positive	Positive	Very positive
When ammonia is used to generate energy, it is converted again into water and air so it would not contaminate					
There is ammonia infrastructure in place all around the world					
The penetrating smell of ammonia is an excellent option to detect any gas leak					

Animal waste, which contains ammonia, could be utilized instead of polluting soil and aquifers

AMMONIA IN MEXICO (OR UK)

Would you support or oppose the use and development of green ammonia technologies in your country as a way to reduce carbon emissions?

- Strongly support
- Somewhat support
- Neither support nor oppose
- Somewhat oppose
- Strongly oppose

How feasible do you think this kind of projects might be developed in Mexico?

- Not feasible at all
- Probably not feasible
- Not sure
- Probably feasible
- Definitely feasible

If we use this technology in Mexico (or UK), who would you trust to regulate it?

- Government
- Industry
- Both
- None

Is there anything we've missed - anything you'd like to tell us that would help us to understand your opinions about climate change and green ammonia?

IMPORTANT: PLEASE PRESS SUBMIT TO COMPLETE THE SURVEY

Thank you for completing our survey! This survey is part of a cross-national comparison of public perceptions of climate change and new energy technologies. In this survey you were asked about your personal attitudes towards the use of ammonia as an energy vector, for power distribution and storage in order to help mitigate climate change. We want to find out how supportive people would be about research in this area, and ultimately deployment in the future.

This survey was designed to identify how public perceptions of climate change and ammonia-based technologies differ between Mexico and the UK. All data will be held totally anonymously, so that it is impossible to trace this information back to you individually. This information may be retained indefinitely and will be made available for research purposes.

For more details or concerns about the wider project you can contact:
Researcher: Andrea Guati Rojo MercadoGuatiRojoA1@cardiff.ac.uk
Supervisors: Dr. Christina Demski DemskiCC@cardiff.ac.uk
Supervisor: Dr. Agustin Valera- Medina: valeramedinaA1@cardiff.ac.uk

Who is funding the research?
The Research is funded by the National Council of Science and Technology in Mexico (abbreviated CONACYT). This entity is in charge of the promotion of scientific and technological activities, setting government policies for these matters and granting scholarships for postgraduate studies.

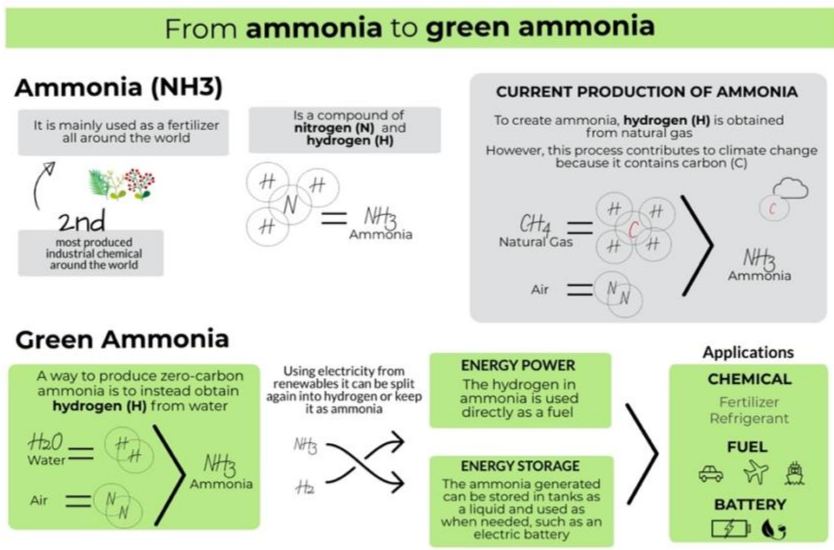
If you would like more information about ammonia-based systems you can access the following link: https://www.youtube.com/watch?v=eLMfRZGagfE

Please contact the School of Psychology Ethics Committee if you have any concerns regarding this research: Secretary of the Ethics Committee, School of Psychology, Cardiff University, Tower Building, Park Place, Cardiff, CF10 3AT, Email: psychethics@cardiff.ac.uk Privacy notice: The information provided on the consent form will be held in compliance with GDPR regulations. Cardiff University is the data controller and Matt Cooper is the data protection officer (inforequest@cardiff.ac.uk).

Appendix C.2 – Questionnaire structure by topics

1. Demographics (Q.1- 6)
2. Perceptions of climate change (Q.8 – 13)
3. Pro-Environmental Behaviour (Q.14)
4. Overpopulation (Q.15)
5. Climate change knowledge
   - Knowledge about nergy sources (Q16 -17)
   - General Knowledge (Q18 -19)
6. Green Ammonia
   - First associations (Q.7)
   - Initial responses (Q.20 -21)
   - Risk and Benefits (Q.22 -26)
7. Ammonia in their country´ (Q.27 – 29)

Appendix C.3. – Graphic in the survey



Appendix C.4 – Questionnaire structure by topics

8. Demographics
9. First Associations
10. Perceptions of climate change
11. Pro-environmental Behaviour
12. Fuels
    a. Fuels' knowledge (Q16 -17)
    b. Support of fuels (Q18 -19)
13. Green Ammonia
    a. Risk and Benefits
14. Ammonia in the UK (or Mexico)

Appendix C.5 – Tables for demographic profile of participants

a) Q.2 Age

	UK (N=357)	Mexico (N=563)
18-24 (+1)	20	58
25-34 (+2)	118	228
35-44 (+3)	65	131
45-54 (+4)	79	60
55-64 (+5)	51	64

65+ (+6)	24	22
Mean score	**3.27**	**2.84**

b) Q.5 Political orientation

	Survey UK (N= 353)	**Survey Mexico (N= 558)**
0	22	13
1	30	7
2	53	22
3	84	50
4	32	59
5	61	130
6	26	68
7	29	78
8	9	74
9	2	27
10	5	30
Mean score	**5.69**	**3.77**

c) Q.6 Region

Value	**Code**	**Region**	**Percentage**
1	Nothing/Don't know		0.10
United Kingdom[45]			
2	Scotland		6.5
3	Northern Ireland		0.8
4	North East	*Co Durham, Northumberland, Tyne & Wear and the Tees Valley*	*0.8*
5	North West	Lancaster, Cheshire, Manchester *Cheshire, Cumbria, Greater Manchester, Lancashire and Merseyside.*	2.3
6	Yorkshire and the Humber	*North Yorkshire, West Yorkshire, South Yorkshire, East Riding, North Lincolnshire and North East Lincolnshire.* Hull	*2*
7	East Midlands	*Derbyshire, Leicestershire, Lincolnshire, Northamptonshire, Nottinghamshire and Rutland.*	*2*
8	West Midlands	*Birmingham, Herefordshire, Shropshire, Staffordshire, Warwickshire, West Midlands and Worcestershire.*	*5.4*
9	Wales		56.3
10	South West	*Cornwall, Devon, Dorset, Gloucestershire, Somerset, Wiltshire and the Isles of Scilly.* Bristol	*7.6*
11	South East	*Berkshire, Buckinghamshire, East Sussex, Hampshire, the Isle of Wight, Kent, Oxfordshire, Surrey and West Sussex*	*9.3*
12	East of England	*Bedfordshire, Cambridgeshire, Essex, Hertfordshire, Norfolk and Suffolk.*	*1.7*
13	Greater London		4.8
Mexico [46]			

[45] BILES, 2019; NBSO, 2019
[46] Montalvo, 2013

14	Noroeste	Baja California, Baja California Sur, Chihuahua, Sinaloa y Sonora	5.5
15	Noreste	Coahuila, Durango, Nuevo León, San Luis Potosí y Tamaulipas	7.3
16	Occidente	Aguascalientes, Colima, Guanajuato, Jalisco, Michoacán, Nayarit, Querétaro y Zacatecas	10.1
17	Centro	Distrito Federal, Estado de México, Guerrero, Hidalgo, Morelos, Puebla y Tlaxcala	65.5
18	Sureste	Campeche, Chiapas, Oaxaca, Quintana Roo, Tabasco, Veracruz y Yucatán	11.2

Appendix C.6 – Tables for climate change block of questions

a) *Q.8 You may have heard the idea that the world's climate is changing due to increases in temperature over the past 100 years. What is your personal opinion on this? Do you think the world's climate is changing?*

	UK (N=353) %	**Mexico** (N=563) %
Definitely changing (+1)	88.7	95.4
Probably changing (+2)	10.7	3.9
Probably not changing (+3)	0.6	0.4
Definitely not changing (+4)	0	0.4
Mean Score	**3.88**	**3.94**

b) *Q.9. How worried, if at all, are you about climate change?*

	UK (N=353) %	**Mexico** (N=563) %
Not at all worried	1.4	.5
Not very worried	7.6	2.7
Fairly worried	30.1	28.6
Very worried	35.1	49.7
Extremely worried	25.8	18.5
Mean score	**3.76**	**3.83**

c) *Q.10. Do you think that climate change is caused by natural processes, human activity, or both?*

	UK (N=353) **%**	**Mexico** (N=563) **%**
Entirely by natural processes	0.8	0.5
Mainly by natural processes	1.7	0.4
About equally by natural processes and human activity	13.1	17.4
Mainly by human activity	72.2	57.2
Entirely by human activity	11.9	24.2
I don’t think climate change is happening	0	0.4

Q.11- How serious of a threat, if at all, is climate change to each of the following?

	Not at all serious	**Not very serious**	**Fairly serious**	**Very serious**	**Extremely serious**

	UK	Mexico	**%**	UK	Mexico	**%**	UK	Mexico	**%**	UK	Mexico	**%**	UK	Mexico	**%**
You and your family	3.1	0.2	**3.3**	16	3.6	**19.6**	38.5	26.5	**65.0**	32.6	52	**84.6**	9.8	17.8	**27.6**
UK/Mexico as a whole	0.8	0.4	**1.2**	9.6	1.2	**10.8**	30.7	13.5	**44.2**	41.7	52.9	**94.6**	17.2	32.0	**49.2**
People in developing countries	0.6	0.5	**1.1**	3.4	1.8	**5.2**	14.3	9.8	**24.1**	32.9	44.8	**77.7**	48.9	43.1	**92**
People in developed countries	0.8	0.9	**1.7**	8.7	4.4	**13.1**	29.0	24.6	**53.6**	44.2	47.3	**91.5**	17.2	22.8	**40**

d) *Q.15 What do you think about limiting the number of children per family as a measure to tackle climate change?*

		UK % (N= 357)	**Mexico % (N=562)**
1	Strongly agree	17.4	42.9
2	Tend to agree	28.6	19.9
3	Neither agree nor disagree	23.5	19.6
4	Tend to disagree	14.3	7.7
5	Strongly disagree	16.2	10
		M=3.17, SD=1.32	**M=3.78, SD=1.33**

e) *Q.16 Do you believe the following fuels/energy sources contribute to climate change?*

Fuel	**UK % (N=357)**				**Mexico % (N=563)**			
	Contributes	It does not contribute	Don't know	I've never heard of it	Contributes	It does not contribute	Don't know	I've never heard of it
Biomass	39.4	17.1	34.7	8.4	26.3	15.1	19.4	39.3
Coal	92.7	2.2	5.0	-	81.5	11.2	6.2	1.1
Diesel	96.1	2.0	2.0	-	86.3	10.7	2.5	0.5
Gasoline	94.1	2.0	3.9	-	87.4	11.0	1.4	0.2
Hydrogen	26.9	30.0	42.0	1.1	31.6	26.3	35.7	6.4
Natural Gas	72.5	7.0	20.5	-	65.1	18.2	16.4	0.4
LP Gas	61.3	2.5	26.1	10.1	73.0	12.3	13.5	1.2
Nuclear	43.1	34.2	22.7	-	58.4	25.8	14.6	1.2
Biofuels	43.4	24.9	31.4	0.3	39.6	42.8	14.4	3.2
Hydroelectric energy	19.0	68.3	12.0	0.6	32.9	55.5	11.0	0.5
Wind energy	15.2	78.4	6.2	0.3	22.0	71.0	6.4	0.5
Solar energy	15.7	79.8	4.2	0.3	20.9	67.0	7.0	5.2
Tidal energy	12.4	77.2	8.7	1.7	18.5	52.1	18.7	10.7

f) Q.17. To what extent, do you support or oppose the use of…

	UK % (N=355)					
	Strongly support	Support	Neither support nor oppose	oppose	Strongly oppose	I've never heard of it
Biomass	8.5	29.3	38.9	3.7	3.1	16.6
Coal	.8	3.4	20.4	33.9	40.9	0.6
Diesel	1.1	4.2	27.7	39.5	27.5	-
Gasoline	1.1	4.5	33.6	39.5	20.4	0.8
Hydrogen	11.2	29.5	46.9	5.3	2.2	4.8
Natural Gas	2.3	17.8	44.6	23.4	10.2	1.7
LP Gas	1.7	6.5	45.8	20.2	11.8	14.0
Nuclear	7.3	18.3	28.7	22.0	23.1	.6
Biofuels	11.0	36.0	38.5	6.5	3.9	4.2
Hydroelectric energy	42.8	38.6	13.2	2.5	1.4	1.4
Wind energy	57.5	36.6	5.1	0.3	0.3	0.3
Solar energy	59.6	34.2	5.1	0.6	0.3	0.3
Tidal energy	53.2	34.9	7.6	0.3	0.3	3.7
Fuel	**Mexico % (N=563)**					
	Strongly support	Support	Neither support nor oppose	oppose	Strongly oppose	I've never heard of it
Biomass	17.9	15.1	11.7	2.1	1.2	51.9
Coal	2.7	13.1	15.1	30.4	35.7	3.0
Diesel	3.0	17.8	15.5	37.4	25.1	1.2
Gasoline	2.3	20.3	14.2	40.6	21.7	0.9
Hydrogen	19.6	21.4	23.2	12.1	4.5	19.3
Natural Gas	14.6	33.5	21.9	21.4	6.4	2.3
LP Gas	3.6	29.4	22.6	28.6	11.9	3.9
Nuclear	10.3	24.9	14.2	14.6	30.8	5.2
Biofuels	46.8	26.7	11.2	5.0	3.0	7.3
Hydroelectric energy	58.1	26.0	8.0	3.9	1.2	2.7
Wind energy	81.3	11.0	4.1	1.1	0.7	1.8
Solar energy	75.4	11.4	4.6	0.9	0.2	7.5
Tidal energy	56.4	12.1	11.7	1.1	-	18.7

g) Q.17 (b) Mean responses for fuel support

Fuel		***Mean***	***SD***	***t-test, two tailed***[47]	*Cohen's d*
Biomass	Mexico	3.96	1.01	t(565)= 6.651, p < 0.001	0.56
	UK	3.44	0.87		
Coal	Mexico	2.14	1.14	t(899)= 3.536, p < 0.001*	n/a
	UK	1.89	0.90		
Diesel	Mexico	2.35	1.13	t(910)= 3.299, p < 0.001*	n/a
	UK	2.12	0.89		
Gasoline	Mexico	2.40	1.10	t(909)= 2.110, p= 0.026	n/a

[47] *Bonferroni correction top=0.003*

	UK	2.26	0.87		
Hydrogen	Mexico	3.49	1.17	t(790)= 0.632, p < 0.528	n/a
	UK	3.44	0.85		
Natural Gas	Mexico	3.29	1.15	t(895)= 6.906 , p < 0.001	0.47
	UK	2.78	0.93		
LP Gas	Mexico	2.83	1.10	t(844)= 3.099, p < 0.002*	n/a
	UK	2.60	0.88		
Nuclear	Mexico	2.68	1.43	t(884)= 0.338, p=0.735	n/a
	UK	2.65	1.22		
Biofuels	Mexico	4.18	1.05	t(860)= 10.352, p < 0.001	0.72
	UK	3.45	0.93		
Hydroelectric energy	Mexico	4.40	0.89	t(894)= 3.130, p < 0.002	0.21
	UK	4.21	0.87		
Wind energy	Mexico	4.74	0.65	t(904)= 5.257, p < 0.001	0.36
	UK	4.51	0.63		
Solar energy	Mexico	4.74	0.61	t(871)= 4.994, p < 0.001	0.34
	UK	4.53	0.65		

**Not significant when covariates of age, education and political values are considered*

h) *Q.18. To what extent do you think the following statements are correct or incorrect*

Statement	**UK % (N=355)**			**Mexico % (N=486)**		
	Correct	Incorrect	Don't know	Correct	Incorrect	Don't know
Burning oil produces CO2	84.9	2.2	12.9	82.8	3.6	13.7
Nuclear power plants emit CO2 during operation	29.7	37.5	32.8	38.0	28.4	33.6
The global CO2 concentration in the atmosphere has increased during the past 250 years	91.6	2.0	6.4	87	1.2	11.7
The last century's global increase in temperature was the largest during the past 1,000 years	81	2.0	17.1	80.3	1.6	18.1

i) *Q.19. For the next decades, the majority of climate scientists expect…*

Statement	**UK % (N=345)**			**Mexico % (N= 549)**		
	Correct	Incorrect	Don't Know	Correct	Incorrect	Don't know
…an increase in extreme events, such as droughts, floods and storms	96.1	0.6	3.4	95.7	1.8	2.5
…the climate to change evenly all over the world	18.2	68.9	12.9	41.9	44.6	13.5

j) *Chi-square analysis for fuel knowledge (Q.17)*

Energy sources	**Chi-square analysis**	**Description of key differences according to residuals analysis**
Biomass	$\chi(3) = 108.940$, $p < .001$	Mexico less likely to say biomass contributes to CC than the UK and more likely to say they have never heard of biomass. The UK respondents were more likely to say they don't know compared to Mexico.

Coal	$\chi(3) = 30.278$, $p < .001$	Respondents from both countries tend to say coal contributes to CC but the UK was less likely to say it doesn't contribute compared to Mexico.
Diesel	$\chi(3) = 27.238$, $p < .001$	Same pattern as for coal.
Gasoline	$\chi(3) = 31.359$, $p < .001$	Same pattern as for coal.
Hydrogen	$\chi(3) = 18.967$, $p < .001$	Mexican respondents were slightly more likely to say they had never heard of hydrogen.
Gas	$\chi(3) = 24.653$, $p < .001$	Mexican respondents were more likely to say gas contributes to climate change than in the UK.
LP gas	$\chi(3) = 84.023$, $p < .001$	Mexican respondents were more likely to say LP gas contributes to climate change compared to the UK. They were less likely to say they do not know and never heard of.
Nuclear	$\chi(3) = 27.654$, $p < .001$	Mexican respondents were more likely to say nuclear contributes to climate change and the UK respondents were more likely to say they do not know.
Biofuels	$\chi(3) = 59.281$, $p < .001$	UK respondents were less likely to say it contributes to climate change and more likely to say they do not know compared to Mexican respondents.
Hydroelectric	$\chi(3) = 21.397$, $p < .001$	Mexican respondents were more likely to say it contributes to climate change.
Wind energy	$\chi(3) = 7.210$, $p = .065$	
Solar	$\chi(3) = 26.635$, $p < .001$	Mexican respondents slightly more likely to say they had never heard of it.
Tidal	$\chi(3) = 66.461$, $p < .001$	The UK respondents were more likely to say it doesn't contribute to climate change and less likely to say they do not know or never heard of it.

Appendix C.7: Tables for green ammonia questions

a) Q.7. *What are the first thoughts or images that come to mind when you hear the term 'ammonia'?*

Value	Coding	Description	Results (%)
1	Nothing/don't know	Don't know, unsure, NA, nothing, none/ have no idea/nothing comes to mind	1.1
2	Poison	Any mention of ammonia being poison, toxic, an acid, corrosive	17.4
3	Smell	Responses about the smell. Penetrating smell/smells horrible /unpleasant	14.1
4	Safety	Any mention of not being safe/dangerous or bad for humans	8.6
5	Chemical	Any mention of ammonia chemical properties. A chemical/ nitrogen/hydrogen/NH3/NH4	18.4
6	Cleaning product	Any mention as a product for cleaning/bleach/disinfectant	15.4
7	Urine/manure	Any mention of urine/faeces/manure/animal or human waste/yellow liquid	7.1
8	Pollutant	Mentions of an impact to the environment pollutant/ bad for the environment	2.1
9	Death	Death/killing/kidnapping/bombs/blood	.8
10	Fuel	Energy/clean fuel	1.1
11	Industry	Fertilizer/refrigerant	3.7
12	Other products	Hair products/painting/tanning	2.5

13	Negative	Open concepts expressing negative feelings concepts like terrible/bad	0.3
14	Substance	Broad idea of ammonia such as gas/substance	0.5
15	Confusion with other chemicals or fuels	"Kitchen gas" (natural gas)/ "swimming pool" (chlorine)/ "Biodigester" (Biofuels)	1.5
20	Other	Any code that does not fit elsewhere.	1.5
99	Misc	Responses that don't make sense, reword question, do not answer question.	1.5

b) *Q.20 Please tell us what thoughts or images came to mind when reading this information about green ammonia?*

Value	**Coding**	**Description**	**Results (%)**
1	Nothing/don't know	Don't know, unsure, NA, nothing, none/ have no idea/nothing comes to mind	5
2	Poison	Any mention of poison, toxic, acid, corrosive	1.3
3	Smell	Responses about the smell/ penetrating smell or odour	0.5
4	Safety/dangerous	Any mention of not being safe/dangerous or bad for humans	1.4
5	Solution/alternative	Reference as "the solution"/promising/an alternative/progress/potential	7.9
6	Novel concept	New for me/ I've never heard about it before/ I didn't know about this/surprised/wow	14.7
7	Cost	Mentions of being costly, expensive	1.0
8	Pollutant	Mentions of a negative impact to the environment pollutant/gas bad for the environment	0.7
9	Complex/Confusing	Any reference to being confused, puzzled, too complicated	2.5
10	Need more information	Any mention of needing more information. Queries about what it is and how it works	3.6
11	Water	Any reference to water, water quality, shortages	0.9
12	Positive for environment	Good option for the environment/good green fuel/less pollution	8.9
13	Negative	Open concepts expressing negative feelings concepts/terrible/bad	2.1
14	Positive	Open concepts expressing positive feelings. Sounds promising/looks like a good idea /interesting/great idea/amazing/impressive/beneficial	33.8
15	Sceptical	Weird, I don't believe it. Not sure it can work. It will end up being like any other technology	7.5
20	Other	Any code that does not fit elsewhere. Important/security	2.5
99	Misc	Responses that don't make sense, reword question, do not answer question.	5.8

c) *Q.22 How positive do you feel about the following benefits…?*

Benefit	**UK**		**Mexico**		**t-test, two tailed**[48]
	Mean	SD	Mean	SD	

[48] Bonferroni correction to p=<0.012

When ammonia is used to generate energy, it is converted into water and air so it would not contaminate the environment	4.25	0.82	4.35	0.79	t(870)=1.65, p= 0.099
Infrastructure to use ammonia is already in place around the world	4.05	0.92	4.13	0.84	t(818)=1.28, p= 0.199
The penetrating smell of ammonia is a useful way to detect any gas leak	3.67	0.84	3.98	0.85	t(875)=5.13, p= 0.000, Cohen's *d* = 0.36
Animal waste, which contains ammonia, could be utilized to create energy instead of polluting soil and water	4.12	0.82	4.30	0.76	t(881)=3.38, = 0.001, Cohen's *d* = 0.23

d) *Q.23 To what extent are you worried about the following risks…*

Risk	**UK**		**Mexico**		**t-test, two tailed**[49]
	Mean	SD	Mean	SD	
Ammonia is a toxic gas that when inhaled in large concentrations can cause burns in eyes and mouth	3.32	0.89	3.64	0.88	t(887)=5.24,p=0.000, Cohen's *d* = 0.36
As a fuel, if ammonia is not burned properly, NOx particles (a type of greenhouse gas) can be released, contributing to climate change	3.55	0.79	3.82	0.81	t(875)=4.84,p=0.000, Cohen's *d* = 0.34
Ammonia technology to store and generate energy would need large investments to commercialize, this might imply higher prices in electricity	2.98	0.89	3.63	0.85	t(743.45)=4.87, p=0.000, Cohen's *d* = 0.75
Ammonia has a very unpleasant smell	2.79	1.03	3.14	1.10	t(888)=4.69, p=0.000, Cohen's *d* = 0.32
Ammonia technology is water intensive so it would need to be developed in areas with easy access to water	3.04	0.99	3.86	0.93	t(869)=12.20, p=0.000, Cohen's *d* = 0.85

e) *Q.24 On the whole, how acceptable or unacceptable are the risks of green ammonia to you?*

	Mean	**SD**	**t-test, two tailed**
UK	3.40	0.73	t(904) = - 3.66,*p* = 0.000, Cohen's *d* = -0.25
Mexico	3.59	0.74	

f) *Q.25 Do you think there are more risks or benefits for green ammonia?*

	UK	**Mexico**	
	M=2.30, SD= 0.72	M= 2.30 SD= 0.74	t(904)= 0.16, p= 0.87
The risks outweigh the benefits	15.8%	17.4%	
The risks and benefits are about the same	39%	34.8%	
The benefits outweigh the risks	45.3%	47.8%	

g) *Q.26 Do you have any other concerns about ammonia?*

Value	**Code**	**Description**		**Results (%)**	
			UK	Mexico	Total

[49] Bonferroni correction to p=<0.01

1	Nothing/don't know	Don't know, unsure, NA, nothing, none/ have no idea/nothing comes to mind	63.2	65.3	64.5
2	Poison	Any mention of poison, toxic, acid, corrosive	0.8	0.2	0.4
3	Smell	Responses about the smell/ penetrating smell or odour	0.6	0	0.2
4	Safety of the technology	Any mention of the safety behind the technology	2	3.4	2.8
5	Acceptability	Any mention to public and acceptability/education	0.8	1.2	1.1
6	Legislation	Politics/government/laws/control/corruption	2.5	3.9	3.4
7	Cost	Being expensive	1.7	3.2	2.6
8	Negative for the environment	Mentions of a negative impact to the environment air pollutant/gas bad for the environment/NOx	2.8	1.4	2
9	Complex/Confusing	Any reference to being confused, puzzled, too complicated	0.8	0	0.3
10	Need more information	Any mention of needing more information to decide. Queries about what it is and how it works	4.5	4.8	4.7
11	Water usage	Any reference to water, water quality, shortages	5.1	6.6	6
12	Water pollution		0.6	1.4	1.1
13	Negative	Open concepts expressing negative feelings concepts/terrible/bad	0.6	0.5	0.5
14	Positive	Positive comments	0.8	0.7	0.8
16	Alternatives	Mentions of other solutions. Better invest in other technologies/other technologies are better	0.2	0	0.8
18	Risk/benefit evaluation	Further risk/benefits evaluation/Long term evaluation/trials	3.9	1.1	2.2
19	Logistics	Any mention to production/storage/distribution/time required	3.7	2.3	2.8
20	Other	Any code that does not fit elsewhere. Important/security	0.8	0.9	0.9
21	Impact on human's health	Everything mentioning safety for people. Cancer/diseases/impact to communities	2.2	2.5	2.4
22	Development	Will be hard to develop/	0	0.2	0.1
99	Misc	Responses that don't make sense, reword question, do not answer question.	0.6	0.2	0.3

Appendix C.8: Tables for the development of the technology in UK/Mexico

a) *Q.27 Would you support or oppose the use and development of green ammonia technologies in your country as a way to reduce carbon emissions?*[50]

	Mean	**SD**	**t-test, two tailed**
UK	3.93	0.88	$t(913) = -0.72$, $p = .468$
Mexico	3.97	0.81	

[50] 1.- Strongly Oppose 2.- Somewhat oppose 3.- Neither support nor oppose 4.- Somewhat support 5.- Strongly support

b) *Q.28 How feasible do you think the development of this kind of project (e.g., ammonia technologies)*

might be in the UK?

	UK %	Mexico %
Definitely feasible	17.2	8.4
Probably feasible	46.9	28.5
Not sure	30.8	29.6
Probably not feasible	4.5	25.3
Probably feasible	0.6	8.2

c) *Q.29 If we use this technology in the UK, who would you trust to regulate it?*

	UK %	Mexico %
Government	29.7	3
Industry	4.8	44.6
Both	43.8	35.1
None	21.8	17.3

Appendix C.9 – Regressions

a) Linear regression analysis of CC risk perception

	UK			Mexico		
Independent Variables	***B***	**SE**	**p**	***B***	**SE**	**p**
CC worry	0.003	0.056	n.s.	0.001	0.052	n.s.
CC threat	0.202	0.071	**	0.096	0.064	n.s.
Risk and benefits of ammonia systems	0.450	0.054	***	0.608	0.043	***
R^2	0.214					
Adj.R^2	0.207					

Unstandardised regression coefficients (B) and standard errors (SE).
n.s. (non-significant). p < 0.05*, p < 0.01**, p< 0.001 ***

b) Linear regression analysis of energy security concern (sociodemographic)

	UK			Mexico		
Independent Variables	***B***	**SE**	**p**	***B***	**SE**	**p**
Gender	-0.336	0.101	***	-0.185	0.079	*
Age	-0.069	0.041	n.s.	-0.025	0.039	n.s.
Working Status (Unemployed)						
Employed	0.029	0.213	n.s.	-0.093	0.174	n.s.
Student	0.022	0.245	n.s.	-0.047	0.210	n.s.
Political Orientation	-0.018	0.022	n.s.	0.055	0.018	**
R^2	0.031					

Adj.R^2	0.046

Unstandardised regression coefficients (B) and standard errors (SE).
n.s. (non-significant). p < 0.05*, p < 0.01**, p< 0.001 ***

c) Multiple regression analysis of sociodemographic and theoretical variables

		UK			**Mexico**		
	Independent Variables	***B***	**SE**	**p**	***B***	**SE**	**p**
Socio-demographic variables	Gender	- 0.341	0.094	***	- 0.015	0.070	*
	Age	- 0.017	0.039	n.s.	- 0.042	0.034	n.s.
	Working Status (Unemployed)						
	Employed	0.028	0.194	n.s.	- 0.075	0.153	n.s
	Student	0.051	0.224	n.s.	- 0.073	0.184	n.s.
	Political Orientation	0.011	0.021	n.s.	0.053	0.016	***
Theoretical Variables	CC worry	0.075	0.065	n.s.	0.067	0.055	n.s.
	CC threat (You and your family, your country, developing country and developed countries)	0.170	0.082	*	0.068	0.066	n.s.
	Risk and benefits of ammonia systems	0.367	0.061	***	0.572	0.046	***
	R^2	0.226			0.288		
	Adj.R^2	0.203			0.275		

Unstandardised regression coefficients (B) and standard errors (SE).
n.s. (non-significant). p < 0.05*, p < 0.01**, p< 0.001 ***