



Universidad Popular Autónoma del Estado de Puebla

Centro Interdisciplinario de Posgrados

Investigación y Consultoría

Departamento de Ingeniería

Doctorado en Planeación Estratégica

y Dirección de Tecnología

Strategies to achieve a successful energy transition in Mexico:
From fossil to renewable energies.

Thesis to obtain the degree of Doctor in
Strategic Planning and Technology Management

Presents

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Puebla, México.

2020



UPAEP – Secretaría General

Dirección General de Apoyos Académicos

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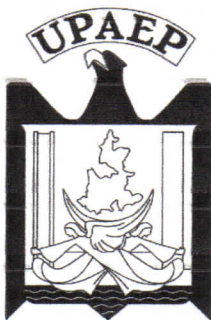
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Se aprueba la Tesis:

Estrategias para alcanzar una transición energética exitosa en
México: de energías fósiles a renovables.

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17 de Diciembre de 2019

Dedication

”For God so loved the world that he gave his one and only Son, that whoever believes in him shall not perish but have eternal life” -John 3:16

To the lord my Father, who has always been there with me;

To my dear dad Fallito, whose entire life and love were dedicated to raising his children along the path of good;

To my mom Toña, who offered her life to bring three extraordinary children into the world;

To my beloved wife Rocío, who has been by my side for twenty two years and together we have bred two fantastic children: the great Rafi, who teaches us the simplicity of life and pure goodness every day and, the incredible Iker, who God entrusted him with the enormous task of being the brother of a special child, a task that he has far exceeded it;

To my brother Fer, who has become my best friend and with his nobility has kept the family together;

To my sister Dany, who, even been an orphan since baby, has shone in life;

To my little siblings Mony, Iñaqui and Maryfer for being an important part of my life.

Acknowledgements

"The only constant in life is the change"-Heraclitus

A special acknowledge to my thesis Director: Dr. Damian Emilio Gibaja Romero, a gentleman that even being very young has a deep scientific knowledge and a mastery of the academy; guiding me across four years of Ph.D. studies;

To my thesis advisors: Dra. Katy Ovando, correcting me across methodology and style, and with whom I have a very special affection and, Dr. Luis Barrera, who with his technical advice enriched my doctoral work;

Finally, I would like to thank affectionately to two great professors: Dr. José Pablo Nuño de la Parra, who motivated me to pursue doctorate studies and was constantly following my evolution in it and, Dra. Betty Pico, my *"Iron Lady"*, whom with firmness, challenges and great wisdom has changed the lives of dozens of doctoral students.

This thesis is about change, and this Ph.D. adventure has changed my life in different ways for good: being a better father, a better husband, a better brother, a better student, a better friend and most important..... a better member of society.

Resumen

En un mundo donde el cambio es la única constante, la transición energética siempre ha estado presente en la historia de la humanidad: desde el descubrimiento del fuego generado por la quema de madera hasta la energía proveniente del sol o del viento, pasando por la energía generada por el carbón y el petróleo. Sin embargo, el mundo se encuentra en constante evolución: la población mundial ha crecido rápidamente y la mayor parte de ella ha migrado a zonas urbanas en busca de mejores condiciones de vida, ocasionando un aumento en la cantidad de energía consumida per cápita proveniente principalmente de fuentes fósiles, lo que ha ocasionado un perjuicio en el medio ambiente.

Con base en acuerdos internacionales, impulsados principalmente por la Organización de las Naciones Unidas, la mayoría de los países han acordado implementar acciones para combatir y revertir el daño ocasionado a nuestro ecosistema encontrando en las fuentes de energía renovables la solución; sin embargo, el desarrollo actual de éstas todavía no es suficiente para satisfacer completamente la demanda mundial de energía. Por lo cual es necesario diseñar un camino estratégico que conduzca de manera exitosa la transición de energías fósiles a renovables.

En el desarrollo de esta tesis, utilizando herramientas cuantitativas y cualitativas, se han identificado las mejores prácticas y los errores cometidos en países más avanzados en el proceso de transición energética y de una manera paralela se han analizado los esfuerzos realizados por el gobierno mexicano en esta materia, a través

de la reforma energética. El resultado de esta investigación es el diseño de una estrategia de transición energética para México que se apoya en dos pilares fundamentales: **un agente impulsor, *el Gobierno***, que dirige, regula y coordina los esfuerzos de los miembros de la cuádruple hélice de la transferencia de tecnología y **un elemento energético intermedio, *el Gas Natural*** que funciona como un puente temporal que cubre la brecha existente entre el consumo y la producción actual de fuentes renovables, con el objetivo de lograr una transición energética exitosa sin afectar la búsqueda de la humanidad por alcanzar cada vez mejores estándares de vida y la sustentabilidad ambiental.

Abstract

In a world where change is the only constant, the energy transition has always been present in the history of mankind: from the discovery of fire generated by burning wood to energy from the sun or wind, passing by the energy generated by coal and oil. However, our world is constantly evolving: the global population has grown rapidly and most of it has migrated to urban areas in search of better living conditions, causing an increase in the amount of energy consumed per capita mainly from fossil sources, which has caused damage to the environment.

Based on international agreements, mainly promoted by the UN, most countries have agreed to implement actions to combat and reverse the damage caused to our ecosystem by finding the solution in renewable energy sources; however, the current development of these is still not enough to meet the world's energy demand. Therefore, it is necessary to design a strategic path that successfully leads the transition from fossil to renewable energies.

In the development of this thesis, through the use of quantitative and qualitative tools, the best practices and mistakes made in more countries advanced in the process of energy transition have been identified and, in parallel, the efforts made by the Mexican government, through the energy reform have been analyzed. The result of this research is the design of an energy transition strategy for Mexico that is based on two fundamental pillars: **a driving agent, *the Government***, which directs, regulates and coordinates the efforts of the members of the quadruple helix

of technology transfer and **an intermediate energy element, *the Natural Gas***, that functions as a temporary bridge that covers the gap between current consumption and production of renewable sources, with the objective to reach a successful energy transition without affecting humanity's quest to achieve ever better living standards and environmental sustainability.

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Introduction

With the current uncertainty of the available reserves of oil and the growing demand of global consumption of this energy, alternative energies have strongly called attention as a potential option to develop and thus avoid facing a future with problems of energy supply from oil. And also, to combat the adverse climate effect that has been generated with the increase in the per capita consumption of this energy and its derivatives in the world (EIA, 2016).

Oil global production and consumption (million of barrels per day)

Production & Consumption	2014	2016	2018
Global Production	93.4	96.2	96.8
Global Consumption	92.5	95.4	96.8

Table 1: World production vs. world consumption of oil products (EIA, 2016).

Table 1 shows how the gap between the production and the daily consumption of barrels of oil has been reduced every year, reaching an even point in the year 2018. If this trend continues, there will be a deficit between consumption and production within the next five years. On the other hand, global trends such as climate change, greenhouse effects and the global warming are driving the increase in the adoption and use of new energy sources (Yousuf et al., 2017; Klose et al., 2010). In the aspect of global warming, term used to describe the gradual increase of the average temperature of the atmosphere of the earth and its oceans, there is a debate about whether it is real, or just a cyclical behavior of the earth. However, based on data from scientists monitoring the climate for decades, it has been agreed that the planet, in effect, is heating up (Hansen et al., 2010).

In Figure 1 we observe that the scientific consensus on global warming indicates that the average temperature of the earth has increased between 0.4 °C and 0.8 °C during the last 100 years (Hansen et al., 2010). The increase in the volumes of carbon

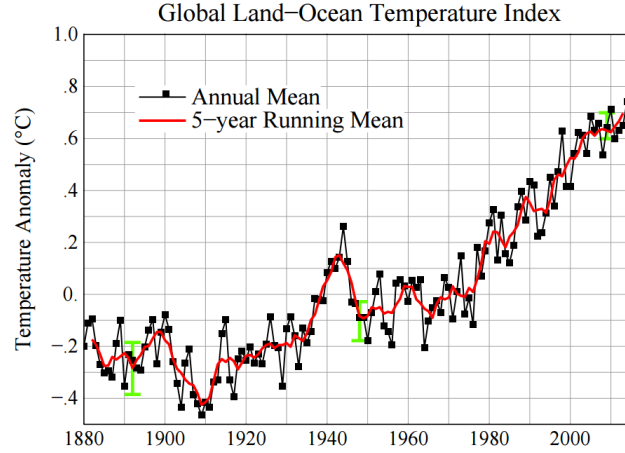


Figure 1: Global warming in the last 100 years. (Hansen, 2010).

dioxide and other greenhouse gases released by burning fossil fuels, agriculture and other human activities, are the main sources of global warming that has occurred in recent years (Folland et al., 2001).

International organizations aware of this trend have sought to reach agreements that reconstruct the climatic conditions. The first important global attempts were those that took place in Kyoto and Bali and, recently, during the Conference of Parties 21 (COP 21) meeting in Paris in 2015 (UN, 2016), where they were able to gather and commit most of the countries of the world to seek that the increase in the temperature of the planet stops below 2°C and has committed the signatories, members of the United Nations, to make efforts to reduce the temperature of the oceans by 1.5°C , a temperature comparable to that registered before the First World War. These agreements reflect the urgency of humanity in the face of the threat of drastic climate change manifested in a global ecological and humanitarian crisis.

Gsodam et al. (2005) have come to the conclusion that with the growing need for energy, and the environmental problems that are associated with it, the developed countries are promoting the transformation of current supply systems, focusing more

and more on sustainability and greater use of alternative energies in what is known as the Energy Transition.

Within the spectrum of alternative energies, Natural Gas (NG) has begun to play an important role in the supply of energy worldwide. This, being also a fossil fuel, is generally used to heat, cook or produce electricity in various parts of the world, and to a lesser extent as a fuel for transport (Fei et al., 2014). The current disadvantage of this energy option is that in its natural state -gas-, its transport costs from extraction sources to sources of consumption are high.

However, within the technological advancement in the energy industry, and especially the NG, large energy companies have developed the technology known as Gas to Liquids (GTL), which allows the NG to be converted into a liquid state at ambient temperature, technology that has emerged as a viable option to reduce transportation costs mentioned in the previous paragraph, opening the range of applications thereof, mainly as an option for automotive fuel (Royal-Dutch-Shell, 2016). This technology is already implemented in cities mainly located in developed countries such as Rotterdam in the Netherlands, Paris in France and Berlin in Germany.

National Plans	Strategies	Programs
- National Development Plan.	- National Climate Strategy. - Transition Strategy to promote the use of cleaner technologies and fuels.	- Sectoral Energy Program. - National Program for the sustainable use of energy. - Transition Strategy for Special Program. - National electric system development program.

Table 2: Mechanisms and policies to promote alternative energies (SENER, 2016).

Mexico knows and participates in the global impulse to alternative energies and energy efficiency. Within the National Development Plan (NDP) 2013 - 2018, the creation and promotion of an efficient, fair and more competitive energy market

was formulated, for which it is necessary to develop various financial and technical instruments. This plan contemplates that the country have to join the wave of alternative energies, which has brought with it a growing demand for cleaner and more reliable energy sources. Mexico in this way has positioned itself strategically in the future panorama of alternative energy.

Mexico as a country has also begun to generate a vision towards the greater use of alternative fuels, developing various instruments to promote the use of them, actively promoting them as table 2 above shows.

Contextual Frame

Energy Transition

The energy transition refers to a long-term process in the change of production and consumption mainly from fossil sources so that they are replaced for the most by renewable energies (Rojey, 2009). Energetic transitions have happened continuously in the world, first man used charcoal to produce energy, then with the industrial revolution accelerated its use along with coal, in the early twentieth century the world knew the energy potential of oil and made the transition towards (Rosenow et al., 2017). However, this change can not be made immediately, the development and quantity of renewable energy production are not enough to cover the energy demand required by the world population, a population that in turn grows every day and improves little by little. their life standards require a higher energy consumption (Van Beurden, 2017).

Alternative Energies

According to the EIA (2016) with the global energy demand increasing rapidly, a forecast at a five-year rate of 48% , it is necessary to discover new sources of energy. Taliotis et al. (2014) say that is also important to develop strategies to ensure optimal use. Currently, there is a wide range of alternative energy sources to those

derived from oil, among which are wind energy, solar energy (thermal and photovoltaic), hydro-power, geothermal, biomass and natural gas (Poltronieri, 2016). The intelligent integration of these, specifically in fuels, will not only allow the balance of current consumption from oil, but also complement other technologies to improve the efficiency of the energy system (Reckien et al., 2019). With a the growth of the global population and the energy consumption as well and the knowledge that the reserves of energy from oil are limited and finite in what is known as the "Oil Peak Theory" (Hubbert, 1979; Aleklett et al., 2010; Dale and Fattouh, 2018; Zandvliet, 2011), the alternative fuels have recently emerged as a way to complement the aforementioned hydrocarbon production (Fei et al., 2014; Van Beurden, 2017). However, there is a great challenge for the use of alternative fuels globally, in one case it is similar to the chicken and egg conflict: the existing infrastructure is relatively scarce and therefore the cost of developing them discourages their use, and therefore its low utilization does not generate more resources to develop it (Gupta et al., 2016).

Natural Gas

Natural Gas is a mixture of hydrocarbon gases that are generated by both fossil and anthropogenic resources. Even when natural gas is used as an alternative fuel, concerns about the cost of its storage and distribution have limited the use of this massively (Fei et al., 2014). NG comes from wells or is extracted jointly with oil. Usually when the NG is not required it is injected back into the soil to re-pressurize the well and improve the extraction of oil, or it is burned and vented to the atmosphere directly at the extraction site.

According to the EPA (2002) NG has been considered as one of the cleanest alternative fuels to be used in the energy transition. Its combustion is clean and it is an abundant resource of energy, the main challenge is that its sources of extraction are remote and its high transportation cost (Hall, 2005). Rahmim (2005), estimates that large reserves of natural gas exist in remote or isolated places, where their

extraction and distribution is not economically feasible today. Hix et al. (2012) estimates that NG provides a fifth of the world's energy as of today.

Country & Region	Reserves	Share
Former Soviet Union	2,000	40%
Iran	744	14.9%
Africa	337	6.7%
Asia-Pacific	330	6.6%
South Africa	204	4.1%
Europe	192	3.8%
Saudi Arabia	186	3.7%
Midle east	707	14.1%
USA	163	3.3%
Canada & Mexico	137	2.7%
Total in cubic feet trillions	5,000	100%

Table 3: Estimated global reserves of Natural Gas.
(Samuel, 2003).

Table 3 shows the estimates of NG reserves, which are higher than 5,000 trillion cubic feet, and that reserves can cover the needs of global consumption for the next 60 years (Al-Shalchi, 2006). A 2012 study by the International Energy Agency estimates that NG production will continue to increase, and will represent 25 % of total global energy by 2035. However, today 5% of the production of this gas is vented to the atmosphere or burned at extraction sites in the world, contributing to the greenhouse effect (World-Bank, 2013). This waste represents a cost of 13 billion dollars per year, equivalent to 27% of the US energy consumption. According to Birol et al. (2010), the "golden age of natural gas" is approaching, since its consumption increases globally in all the scenarios analyzed, being already the third

source of energy with 21.5% participation, only behind of oil with 32.3% and coal with 27.3%. However, the NG industry faces a large number of challenges, including high capital costs for infrastructure; the efficiency and reliability of production processes; the volatility of its price; the current markets and players of the oil market; the integration of the production and distribution chain and the global access to these technologies (Woo Park, 2014).

Theoretical Frame

Technology Transfer

According to Bar-Zakay (1971), it is called Transfer of Technology (TT) the process resulting from using an existing scientific or technological innovation in a different context or slightly adapting it to a certain situation. In turn, the concept of Knowledge Transfer (KT) is defined as the process through which a unit (a country, a company, a university, a department, etc.) influences its experience in another unit. The success of TT or KT is measured by the change, for or against, of the unit that receives the knowledge (Argote and Ingram, 2000). The different existing models of Technology or Knowledge Transfer are effective tools to replicate business models that have proved their efficiency and solidity in various industries. This model of Technology Transfer / Knowledge is shown in figure 2.

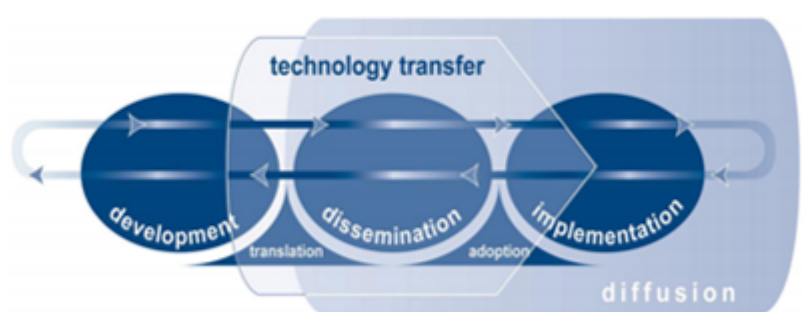


Figure 2: Model for the transfer of technology in the innovation process. (Network Technology Transfer Workgroup, 2011).

The Technology Transfer Helix Model

The model of the quadruple helix, shown in figure 3 is the obligatory reference for the development of a TT model. According to Etzkowitz and Leydesdorff (2000) the components of the original triple helix are the existing relations between the State (E), the Academy (A) and the Industry (I). Thus, the triple helix can be defined as the work performed simultaneously by E, A and I to promote technological development. Recently a fourth helix was added to the model representing society (S), thus constituting the quadruple helix.

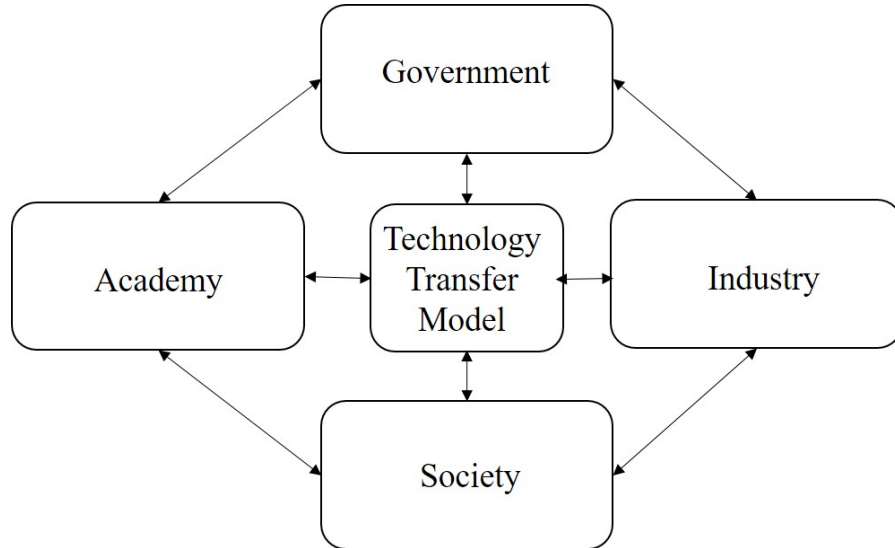


Figure 3: Technology Transfer Helix (own elaboration).

Chapter 1

Purpose and organization

1.1 Problem statement

Mexico can be distinguished within the developing countries by successfully implementing the energy transition process. However, even when there are various governmental and private initiatives willing to help in achieving this transition in a successful way, **”the country doesn’t have an integral strategic approach that impulse the interaction among the four helices of the technology transfer and the use of an intermediate energetic element that allows to reach the ultimate goal of the Energy Transition, moving from fossil to renewables”**.

1.2 Research questions

1. What examples of successful energy transition exist in the world?
2. What are the best practices that can be transferred to Mexico?

3. Which of the four-helix members should take the role of driving agent to successfully achieve the energy transition in Mexico?
4. What should be the strategic approach necessary for identifying the intermediate energetic element to achieve a successful energy transition in Mexico?

1.3 Justification

According to the state of the art analysis, it can be concluded:

- Because at the global level it has been agreed to implement the so-called energy transition, in which production, consumption and energy management are modified.
- Because it is necessary to replace the energy production inputs due to the decrease in the existing oil reserves.
- Because renewable energies represent business opportunities while improving the quality of life of people and the environment.
- Because natural gas has been used successfully as the intermediate element in developed countries to promote the adoption of renewable energy.
- Because in Mexico there has been little collaboration between government, industry, academia and society to generate synergies when designing an energy transition strategy.

1.4 Objectives

1.4.1 General

Design a comprehensive strategic model of technology transfer involving the members of the quadruple helix in the process of the energy transition in Mexico identifying the necessary intermediate (transition) element to successfully achieve it.

1.4.2 Specific

1. Identify the best practices implemented in the countries where the energy transition is most advanced.
2. Understand the current context of the progress of the energy transition process in Mexico.
3. Define which actor of the quadruple helix should be the driving agent responsible for promoting the process of energy transition in Mexico.
4. Establish strategies that identify and involve the transition energetic element as the key intermediate step that will allow to achieve a successful energy transition in Mexico.

1.5 Scope and limitations

The doctoral research to be developed in this document will present the design of the strategic direction focused on the adoption and implementation of the energy transition process by identifying the agent of the quadruple helix that will play the role of the driver intermediary and the energetic transition element that will allow its successful achievement in Mexico.

It will take as its bases the successful experiences developed by countries that have already defined strategies to counteract climate change through the energy transition process (*Strategic Planning*) and the proper functioning of the quadruple helix model (*Technology Transfer*) adapting it to the current situation in Mexico.

1.6 Methodology

The research methodology will be through a deductive, quantitative and qualitative processes, analyzing different agents and contexts.

The development of the strategies are based through three essays referring to the energy transition and a final chapter that synthesize the required strategies for its successful implementation in Mexico.

In the first article we performed a comparative and descriptive analysis of how the different agents of the quadruple helix have successfully interacted in advanced countries during their energy transition process, identifying the best practices of them, such as the identification of the driving agent and the transition element.

In the second article, a quantitative evaluation was performed, through the game theory approach to define which of the four-helix agents needs to play the role of the driving agent to achieve a successful energy transition.

The third article is an analysis and an evaluation performed through qualitative strategy planning tools of the advantages of using Natural Gas as the transition element to smooth and move more efficiently through the energy transition process.

In the last chapter, the conclusions, a synthesis of the three previous chapters was elaborated in order to craft the strategies required for the design of the energy transition process in Mexico.

Chapter 2

Comparison of energy transition initiatives between Germany and the Netherlands through the Quadruple Helix model

2.1 Introduction

The scientific community points out that the global temperature has risen between 0.4 °C and 0.8 °C degrees over the past 100 years (Hansen et al., 2010). So, Governmental Organizations (GO's) and Non-Governmental Organizations (NGO's) have built a shared international agenda to develop and implement international strategies to get control over global warming, through initiatives to move the world energy consumption from fossil fuels to renewable fuels. In other words, the global community pursues a successful Energy Transition (ET) strategy (Stocker, 2014).

Given the importance of ET in fighting against climate change, its achievement requires human and technological resources (Etzkowitz and Leydesdorff, 2000). Em-

pirical and theoretical studies agree that the correct application of such initiatives requires the sharing of technology, and knowledge, between the government, industry, academy and society. In this sense, the Quadruple Helix (QH) Model establishes a theoretical model that establishes strategies to reach technology transference through the collaboration between the previous actors (Yawson, 2009).

Despite the benefits of the QH model, its implementation represents a challenge for decision-makers since sharing property rights over technological patents is not clear when all the QH agents participate in their development (Stocker, 2014). Even more, aside technology transfer, energy transition processes also require economic incentives to motivate the collaboration of all the QH agents; particularly, note that the society and industry have economic incentives to leave the energy transition process given the high costs associated with clean energy production (Yawson, 2009; Kitzing and Weber, 2014; Kalkbrenner and Roosen, 2016). Although the implementation of the QH model presents the previous issues, in the international community, we can find success cases such as Germany and the Netherlands, countries where exist a strong collaboration between the government, society, industry and academy. Even more, both countries are aware that fighting against climate change requires the active participation of all of them (Emelianoff, 2013; Boon and Dieperink, 2014). So, the central aim of this paper is to develop a comparison between Germany and the Netherlands to understand how the QH model can contribute to reaching a proper ET process; we choose these countries given their socio-economic similarities and the fact that both countries fight against climate change via the ET strategy. Our analysis focuses on each QH agent to derive differences and coincidences between Germany and the Netherlands in their ET processes. By performing an exhaustive literature review, we summarise the best practices and the roles that each actor in the QH model plays in both countries.

We find that most of the German initiatives come from the Federal Government,

who incentives the participation of the other agents in the adoption of renewable energies. In the case of the Netherlands, the Academy sector plays a major role in motivating the collaboration from the other actors in the QH model to adopt clean energies. Thus, although both countries base the development of ET initiatives on cooperation between the QH members, we show that their collaboration mechanisms differ given the presence of a “*Driver Intermediary*” in the energy transition process.

This paper is closely related to the literature that suggests the prevalence of the aforementioned *Driver Intermediary*, an agent who leads the definition of strategies to reach a common objective, in the application of the QH model (Matschoss and Heiskanen, 2017).

The present paper is organized into four sections. Section 2 gives a general context of global warming, and the initiatives developed by the international community to fight against it. Section 3 analyses how the QH model performance in Germany and the Netherlands by summarising the activities of each agent that collaborates in the ET process. The last section, Section 4, presents the discussions and conclusions.

2.2 Contextual Frame

In this section, we present the context of the energy transition situation. Thus, we discuss international initiatives that are being implemented to maintain control of the global warming and how the four actors of the QH can interact to reach a better implementation of the of it and obtain a proper phased energy transition.

2.2.1 Energy Transition

The Energy Transition refers to a long-term strategy for the development of political, social, academic and businesses structures that facilitate the adoption of clean

energy. As we mentioned before, its successful implementation implies the adoption of clean energy, those produced with renewable sources, by all energy users in a country (Marchetti, 1980). The main problem in the ET process relies on the fact that clean energy production requires a high investment from producers that imply the imposition of high market prices; in other words, consumers and producer do not have economic incentives to transition from fossil fuels to renewable fuels (Guidolin and Guseo, 2019).

Despite the efforts made by the international community to diminish oil energy consumption, figure 2.1 illustrates that such energy covers a significant portion of the energy demand in the period 1990 to 2040.

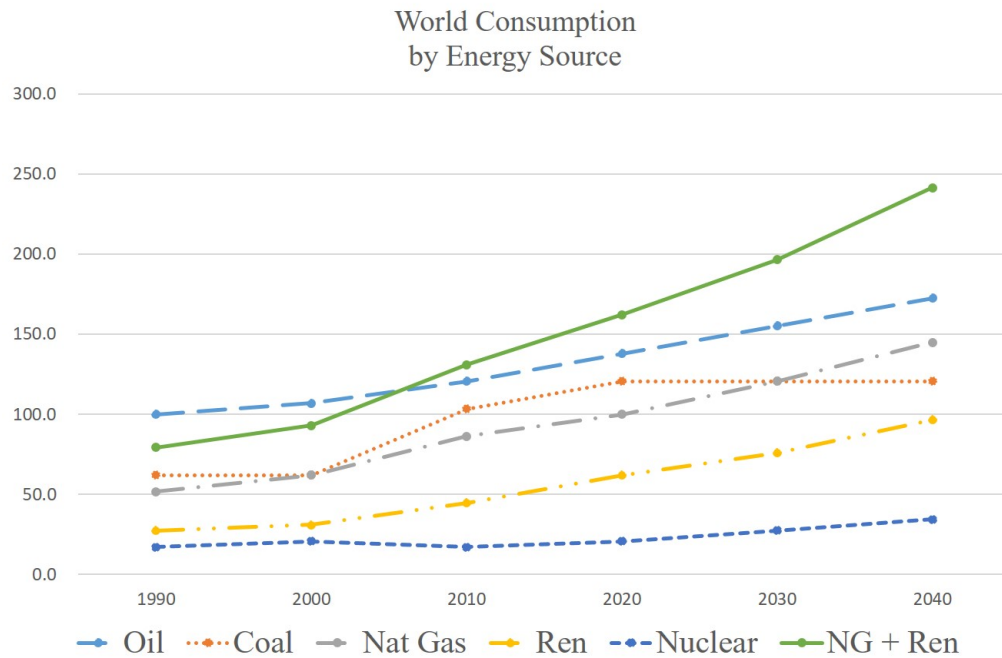


Figure 2.1: World Consumption by Energy Source. Own elaboration with data from the EIA (Indexed data, 1990 Oil source is base 100).

However, the Energy Information Agency (EIA) projects that renewable energy will have a growth spike, by the year 2020, as many energy producers are investing

in the development of renewable energy and will smoothly move to replace fossil sources. Figure 2.1 also shows a decline in energy consumption coming from coal, a primary form of energy, and a steady trend in nuclear energy (EIA, 2016). It is worth noticing that natural gas energy presents a similar trend than renewable energy; the EIA expects that it will become the second source of global energy consumption by the year 2030, which makes it a definite mid step towards the fulfilment of the energy transition.

The same figure 2.1 also shows a decline in energy coming from coal, a primary form of energy, and a steady trend in nuclear energy. It is worth to note that the natural gas, presents a similar growth pace as renewables; the agency expects that it will become the second source of global energy by the year 2030 and a definite mid step towards the fulfilment of the energy transition.

2.2.2 Global Warming

The world population growth also has increased the rate of energy consumption, whose current supply mainly comes from fossil fuels. Among the negative consequences of supplying energy through the use of fossil fuels, the most problematic is the increase of Green House Emissions (GHE), which are the main factors associated with global warming (Mackay, 2019). So, over the last twenty years, the international community has invested a lot of time and resources to develop initiatives to control GHE (Klein et al., 2007).

Renewable energies, also known as the *Golden Energies*, are considered the ideal solution against climate change since they bring benefits for the environment and the society. The rise of the Green Industries will diminish the GHE via the creation of new jobs through the establishment of environmentally friendly firms that use golden energies in their production activities (Poltronieri, 2016).

Despite the positive externalities that the energy transition may generate on

GHE mitigation, it faces financial and social challenges. Nowadays, and in the midterm, the fossil energy industry represents a significant source of employment, income, and profits for many countries; and it is also the cheapest and most accessible energy source for a big share of the global population. Some authors suggest that it is not clear how the green industry may overcome such aspects given the high cost associated with its initial investment (Fagerberg et al., 2016). Moreover, even though there exist efforts to replace energy coming from fossil fuels with renewable energy, there is no general framework that indicates how to succeed in the diminishing of GHE and consequently how to slow/stop climate change (Zimmerman and Faris, 2011). Backstrand et al. (2017) and Geels and Schot (2019) indicate that reaching a total ET may take decades as the current state of renewable sources development does not fill the existing gap between consumption and production (Murphy and Hall, 2011; Aleklett et al., 2010; Al-Shalchi, 2006).

2.2.3 International Initiatives on Climate Change

International efforts on climate change policies began in the early 90's when the United Nations (UN) adopted the United Nations Framework Convention on Climate Change (UNFCCC), and the establishment of the *Kyoto Protocol*, an international agreement to diminish GHE (UN, 1992). Later, the *Berlin mandate*, signed in the spring of 1995, set as its primary objective to reach a consensus over the stabilisation of GHE in the atmosphere (Manne and Richels, 1996). The Berlin Mandate cleared the mechanism to diminish GHE by setting emission targets for the next 20 years in all developed countries. However, no specific objectives were specified for developing countries, which cause criticism around the mandate that caused the negative of countries like the United States to cope with the agreements on it (Den Exter et al., 2015).

Although alliances between government and private organisations emerged to

mitigate the industrial impact on climate change, these were not enough to build international synergies in the first decade of the 2000 years (Zimmerman and Faris, 2011).

In 2015, at the Conference of parties 21 (COP 21) in Paris, a multi-national agreement over climate change was reached, namely *The Paris Agreement*. Its primary objective was to pursue and align different regional and national efforts to set and update targets to control global warming; specifically, the Paris agreement established the goal to keep global temperature increase below 2 °C degrees (EIA, 2016). This conference brought an international hopeful spirit that a paced and structured transition from fossil to renewable energy will be reachable since countries were engaged in developing a global collaborative framework with no social and financial affectations (UN, 2016).

The Paris Agreement was ratified during the COP 22 in Marrakech in November 2016, where the slogan **Together now!** was presented. This meeting reinforced the core message that we are all working along for effective actions to mitigate climate change; also, such slogan boosts the idea that everyone's collaboration is necessary for the 2050 Pathway Platform (UN, 2016). The new mandate pretends that renewable energy sources will become the primary source of energy production/consumption, around the world, by the year 2050. At the same time, the UN is searching for developing a hybrid multilateralism collaboration agenda to develop different dimensions of collaboration such as multi-country; multi-region; GO's and NGO's, public and private industries, multi-university and civil society collaboration. In other words, the UN recognises the necessity of implementing the QH model to cope with COP 21 objectives (Backstrand et al., 2017). Aside the international agreements, there exist regional efforts to diminish GHE and control climate change, Kelemen (2010) considers that the Europe Union (EU) is the leader on the implementation of an efficient energy transition strategy since it plays a significant role in

leading global warming initiatives that motivate other European countries to change energy production processes and consumption (Backstrand and Elgstrom, 2013; Andersson, 2016). Notably, the region is an example of climate control since it has set setting challenging targets on GHE (Heidrich et al., 2016). The EU calls them the 20-20-20 target, which consist of 20% decrease in GHE, 20% increase in energy coming from renewables and 20% improvement in energy efficiency. Given the differences among EU members, these countries individualise the 20-20-20 strategy according to their features and capacity to reach the regional targets (European-Commission, 2015). The region pretends to fulfil these goals by the year 2020. The success of the EU efforts relies on setting regional targets and local objectives as well. In the local level, European cities are taking advantage of the green trend to speed up the development and implementation of the energy transition promoted by the regional climate change initiatives. Through these actions, local governments attract governmental and private financial resources to generate green industries, which generate benefits for the population (Bergman and Bylund, 2012; Jonas et al., 2019). So, local initiatives pursue to diminish GHE but at the same time create new jobs, as well they improve environmental education and the image of city authorities (Andenberg and Clark, 2013; Metzger and Rader Olsson, 2013).

2.2.4 The Quadruple Helix Model

Setting targets from the global to the regional point of view is the first step to reach the objectives of the Paris Agreement. However, given the involvement of different agents with specific objectives, it is necessary to establish a framework that strengthens collaboration among them, which requires high tech capital. So, parallel to the ET, we have a problem of development and implementation of knowledge. In this sense, Etzkowitz and Leydesdorff (2000) introduce the concept of the Triple Helix (TH), a model that responds to the policymakers requisition for technological transfer, and

that enhances the collaboration between the university, government, and industry to spread and apply knowledge.

Therefore, the central aim of the TH model is to implement, in an efficient way, the knowledge generated by universities and industries to increase social welfare. A proper knowledge implementation strength the bonds among all actors and enhances the coordination of the role that each one of them must play (Buehler and Pucher, 2011; Collier and Lofstedt, 1997; Emelianoff, 2013; Hall, 2014). Despite the agents' differences, the TH model emphasises that its agents share structural similarities in the knowledge creation process: universities through academy research, government with public and mission-oriented research laboratories, and the industrials by Research and Development (R&D) departments (Lawton Smith and Leydesdorff, 2014).

In 2009, the Society was added to the Helix model (Yawson, 2009), transforming it into what is now known as the Quadruple Helix (QH). Cavallini et al. (2016) point out that processes leading technology and knowledge transfer improve with the society's participation since its perspective does not only consider the economic impact, it takes care on the social consequences which make the transfer a process more democratic (Arnkil et al., 2010; Woo Park, 2014). However, the interactions between the four agents are characterised by their complexity which implies the arising of conflict due to the particular objectives of each agent.

To avoid conflicts, Matschoss and Heiskanen (2017) identify that one of the actors in the QH model must act as a leader, an agent that they called as the *Driver intermediary* since it makes decisions during the technological transfer process that balance other agents objectives. So, this actor leads and sets a common vision that coordinates and balances the efforts of all actors to produce more efficient results (Jacobson et al., 2017; Villani et al., 2017; Gupta et al., 2007; Lawton Smith and Leydesdorff, 2014; Ranga and Garzik, 2015).

2.3 Comparison of energy transition initiatives between Germany and the Netherlands

In the previous sections, we indicate that the European Union is the leader in the definition and implementation of strategies to fight against climate change via the energy transition strategy. Also, we emphasise on the importance of collaboration among economic agents that participate in the QH model.

In this section, we compare the current status of the climate initiatives that drive the energy transition in Germany and the Netherlands since both countries recognise the importance of adopting new technologies, which also require the QH model implementation to transfer technology that friendly with the environment. So, we compare the initiatives of both countries via the activities that agents, involved in the QH model, perform. It is worth to mention that we choose such comparison given their similarities in climate initiatives concerns, economic development (World-Bank, 2013) and similar human development index HDI (UN, 2016), as the table 2.1 shows.

	Germany		Netherlands		
	World Rank	Measure	World Rank	Measure	
GDP	4	\$3,466,757	18	\$770,845	US million
GDP per capita	19	\$41,936	13	\$45,295	US million
PPP	18	\$48,730	14	\$50,898	US million
Hum. Dev. Ind.	4	0.93	7	0.92	out of 1.00

Table 2.1: Comparison of GDP, GDP per capita, Purchasing Power Parity and HDI. (World Bank, 2017; UN, 2016)

Both countries also share the vision of developing climate initiatives oriented

to reach a smooth energy transition from fossil to renewable energies. They have established private organisations that are in charge of implementing these initiatives to fulfil the objectives derived from the 20-20-20 strategy. Table 2.2 presents the current stage of Germany and the Netherlands in the Energy Transition process; both countries have established similar target for the reduction of greenhouse emission.

Country	GHE 2020 target	As of 2012	EC Current ranking
Germany	14%	24%	3
Netherlands	16%	8%	4

Table 2.2: Green House Emissions GHE targets and currently ranking within the European Commission (own elaboration with data from the European Community, 2012).

2.3.1 Germany and the Quadruple Helix

Below, we describe the activities that involved agents in QH model perform in Germany.

Government

Germany’s government has boosted the replacement of fossil fuels with renewables for around twenty years. The Federal Government has placed a particular focus on environmental policies and now are in the process of being institutionalised across the country (Monstadt, 2004; Bulkeley and Betsill, 2005; Chmutina et al., 2012). In this sense, its main climate initiative programme is the *Energiewende*, which means a change in energy. The Energiewende is a national program that sets targets for GHE for the year 2025 and intends to reach a 100% renewable conversion by the

year 2050 (Scholz et al., 2014). One of the strategies of this program has made that the Germany government sold their shares in energy companies to private investors, and now is the market the one that is driving the ET (Héritier, 2002). Stepping out of their shares in energy production has boosted that new industrials and market niches emerge with the creation of new jobs and new educational curricula (Monstadt, 2019). So, Germany has experimented with an ecological modernisation of energy systems. Also, the German Federal Government has shared and partially delegated the responsibility of climate initiatives implementation to the states through a programme named *Bundeslander* (Bundeskabinett, 2008). The Energiewende and the Bundeslander align GHE targets to the ones agreed with the UN (UN, 2016). Germany had a strong push over nuclear energy, but after the Fukushima incident in 2011, the national approach of moving towards a nuclear power generation in Germany has shifted, and there is active consideration of phasing out that energy and look for a substitute. Natural gas technology is being seemed like the path to the future and has received substantial government support to become the intermediate step between fossil and renewables energies (Joas et al., 2016).

	2000	2010	2020
Oil	100.0	83.6	79.7
Coal	68.0	63.3	62.9
Nat Gas	57.6	60.8	51.5
Renewables	8.8	24.2	33.5
Nuclear	35.4	29.3	19.0
Ren+NG	66.3	85.0	85.1

Table 2.3: Growth of consumption of different kinds of energies in Germany and the advance of renewables (Own elaboration with data from the IEA. Indexed data, the year 2000 Oil source is base 100).

Table 2.3 describes the growth of consumption of different kinds of energies in Germany and the advance of renewables in the past fifteen years, now representing almost one-third of German supply. We note that Germany is moving towards its goals since fossil supply (oil and coal) have decreased in the last fifteen years, while renewables together with natural gas are replacing them with an increasing production path from the first ones.

Industry

The German Industry has seen the transition from fossil energy to renewables with particular scepticism given its high costs; at this moment, the industrial sector requires financial support from the government. In other words, firms' efforts depend on the financial support that subsidies provide. Renewable energy depends on a series of interrelated and interdependent legislations and policies that include cross-governmental or direct subsidies (Sturm, 2017). One example is the cross-subsidy scheme that the country uses for the development of solar panels (Sanz-Casado et al., 2014). In the long term, German industrials are projecting that the clean-tech industry will be developed at a quicker phase and production costs will decline, so it can survive without any subsidies or the need to translate higher price to the end-user. Industry research and development departments are also working on developing new technologies for energy storage to stabilise the supply of renewable energy (The-Economist, 2018).

From the financial standpoint, Chief Financial Officers (CFO's) in the German industry are performing continuous exercises on Net-Present-Value (NPV) about renewable projects. They need to be sure that, in the mid and long-term, financial results are favourable to attract private investors to fund the green industry, namely *green ventures* (Kitzing and Weber, 2014).

Academy

Universities play the role of facilitators or brokers on climate change initiatives (Geels and Deuten, 2019; Hargreaves et al., 2013). An example of a collaborated work with the Industry was the *CLEAN* initiative, a pilot project between institutes of science and the industry (Kuhn et al., 2012). This type of coworking complements the Energiewende policy. The long-term goal of universities is to replace the government as the required link between research findings and their implementation within the industry. Universities have the social prestige to educate and guide citizens in the adaptation of climate initiatives and a strong reputation to properly coordinate the collaboration among QH actors, a partnership that otherwise it would not happen (Joas et al., 2016).

Society

German society plays a vital role thanks to the trend of green projects (private and public funds, coordinated by a group of people, to develop environmentally friendly green enterprises). This kind of projects provides an opportunity for citizens to be part of the energy transition system. Kalkbrenner and Roosen (2016) indicate that people should feel that they can influence government decisions and industry initiatives to reach a fruitful collaboration with the society to the QH objectives.

The Green Cooperatives demonstrate that social collaboration is possible within the energy transition strategy. In these businesses, the German society is actively involved; their functioning requires excellent communication among them, government and the industry. Moreover, the community is the enabler between the central initiatives and their implementation at a local level for the functioning of green cooperatives, i.e., no other agent can manage a cooperative (Boon and Dieperink, 2014; Geels and Deuten, 2019; Hargreaves et al., 2013).

Citizen groups have been shaped in the country, and now, they are seen not only

as an energy consumers both also as active players over the confirmation and transformation of an environmentally friendly energy system (Kalkbrenner and Roosen, 2016). These groups are educating other members of the society on being more efficient in energy consumption. The essence of these groups is the trust existing among them, as they are part of the same community, and share a common concern of a sustainable environment. Also, their structure comes from governmental policies and funds having the incentive that the community owns the cooperative, or remain in a partnership with public or private institutions (Walker, 2008; Walker and Devine-Wright, 2008; Yildiz et al., 2015).

Society faces some challenges as well. Usually, Green Energy is more expensive than energy coming from fossil fuels, and the government cannot provide subsidies for all the population to facilitate the consumption of such energy (Sturm, 2017). Hence, in the case of Germany, part of the society is reluctant to speed up the energy transition because they have to absorb some of the transition costs (Kalkbrenner and Roosen, 2016). Given this problem, the German government is working along with private and public financial institutions to solve this situation creating financial and non-financial incentives that are promoted to fund community energy projects, namely *Green investments* (Bomberg and McEwen, 2012; Monstadt, 2019). These funds pursue to incentive the adoption of renewable energy in a faster pace creating a virtual cycle in which more users will build large-scale economies that will bring the cost of renewable energy down (Castan Broto and Bulkeley, 2013; Kivimaa et al., 2015; Wurtenberger et al., 2011).

2.3.2 The Netherlands and the Quadruple Helix

Now, we review the activities that QH agents perform in the Netherlands. It is worth to mention that the Netherlands is located below the sea level, which makes them especially sensitive to climate change effects (Kabat et al., 2005).

Government

The Netherlands is one of the first countries, together with Germany, that established national climate initiatives (Gupta et al., 2007). Through the National Climate Policy (NCP), the central government develops national strategies including national climate goals, while provinces adopt and implement them at a local scale. For example, there are policies like the Bestuursaccord Nieuwe Stijl (BANS), and the Climate Agenda: Resilient, Prosperous and Green (Den Exter et al., 2015).

The BANS program pursues that public buildings constructions, traffic, transport technologies, housing initiatives and businesses parks have an environmentally friendly design. Also, it actively promotes academic research on sustainable energy (Gupta et al., 2007).

Netherlands climate initiatives are focused on two approaches that complement themselves: **Climate Adaptation**, which goal is the design of the future living, due to the climate change effects; and **Climate Mitigation**, which its core goal is to reduce GHE emissions (The-Hague:Ministry-Of-Economic-Affairs, 2006).

Municipalities are crucial to implement and evaluate any strategy derived from the country's policies. Both government levels have relied on the Academy to get the flexibility for adapting national efforts to a local situation (Reckien et al., 2019).

Table 2.4 shows the path of the oil supply index. It shows a consistently increasing trend in renewable energy production in the Netherlands during the last 15 years. Thus, we can say that energy transition policies, in the Netherlands, were in the right direction by combining the production of renewables and the use of natural gas.

	2000	2010	2020
Oil	100.0	112.1	98.7
Coal	27.7	26.9	38.9
Nat Gas	124.6	139.6	103.0
Renewables	12.8	15.1	18.5
Nuclear	3.6	3.7	3.8
Ren+NG	137.4	154.7	121.5

Table 2.4: Growth of consumption of different kinds of energies in the Netherlands and the advance of renewables (Own elaboration with data from the IEA. (Indexed data, the year 2000 Oil source is base 100)).

Industry

The Dutch industry is aware of the need for reducing their environmental impact in highly populated cities and actively participates in the energy transition process (OECD, 2015). For example, in the transport sector, dutch industry is moving away from diesel to natural gas engines. National and private vehicle fleets, trains and ships in Netherlands ports are examples of how the industrial sectors are moving from fossil to renewable through the natural gas energy (Inoue, 2012). Even more, local industries have joined forces with the municipal government to implement innovative solutions that won't affect the economics of the cities but improve the environmental condition at the same time. Concerning the urban design planning for transport efficiency, the construction sector has adapted its procedures and infrastructure to cope in a better way with environmental requirements (Merk, 2013).

The dutch industry is working closely with universities and research centres to speed up the energy transition (Fusco, 2013). In general, they work closely with other members of the QH model, mainly with the Academy to be technologically prepared for the future environment condition.

Academy

Knowledge institutions, universities and research centres are working very closely with the other actors of the QH in the Netherlands and have taken the leadership to implement climate change control initiatives. They are commanding the development of technologies on CO₂/GHE capture, transport, and storage; searching for energy efficiencies across value chains; and giving advice in developing sustainable entrepreneurship (Castan Broto and Bulkeley, 2013). Schools are integrating knowledge sustainability in all its curricula, and implementing measuring elements that allow auditing the advance over the implementation of these initiatives, in their field and also supervising the implementation of government policies by the industry. One example is the Audit Instrument for Sustainability in Higher Education (AISHE), instrument that today is used by the majority of schools of higher education in the country. Another example is the INHolland University, in which all their students are engaged in sustainability programs during his career, and their research projects must be related to this topic and practised in the industry at least for one scholar period (Rotterdam-Climate-Innitiative, 2009).

Netherlands education system is not only a valuable actor of the QH model; its educational institutions are collaborating as an integrated unit. We could find many examples like the Holland Program on Entrepreneurship (HOPE), in which the Erasmus University of Rotterdam together with the Delft University of Technology and the Leiden University have developed an active and innovative centre for green entrepreneurship (OECD, 2010).

Society

Backstrand and Elgstrom (2013) indicate that dutch society characterises on focusing on cooperation and innovation, features inherent to the Netherlands culture that has risen in an environment with a lack of natural resources and a complex orog-

raphy. Given the active collaboration between industry and academy and a proper direction set by the government, the Dutch society is aware of the importance of reaching a successful ET and have aligned easily with the guidelines imposed by government and academy (Merk, 2013). Dutch society is committed to growth education on sustainability as they understand that the ET will take time they procure to having people more educated on sustainability now and have a better standard of living in the near future (Fenton, 2015).

2.4 Conclusions

In this paper, we develop a comparison of energy transition strategies between Germany and the Netherlands following the interactions established by the QH model. In this comparison, we have found some similarities, like the establishment of a national energy plan or the use of an *Transition Element*, the Natural Gas, that compensates the gap between the energy consumption and the current level of energy produced by renewables. But also differences, mainly related to the agent who drives the initiatives, the *Driver Intermediary*.

In the case of Germany, their energy transition is characterised by an active intervention from the government via a centralised climate program that takes care on providing financial support, for the generation of green enterprises and research on sustainable topics, and the adoption of green energy, via subsidies. Also, we note that the society and the industry play a more passive role since their participation depends on government support. Hence, the Federal Government closely watches over the industry, academy and society activities related to climate initiatives, i.e., the government act as the *driver intermediary* of the QH model in Germany.

Concerning to the Netherlands, we observe that the Dutch academy closely works with the other three members of the QH, all of them have complete trust in edu-

cation institutions. Moreover, the Dutch academy has set up different programs to promote knowledge transfer and implementation with the industry to strengthen the energy transition with the supervision of the central government. Hence, the academy is getting more involved to promote the energy transition by including sustainable topics in their curricula, i.e., it influences society by generating a better-prepared workforce on climate issues. Also, its close relation with the industry and the government has boosted the development of sustainable production processes and public policies to get control over climate changes. Given the impact of the Dutch Academy in the actions of the other QH agents, we conclude that it plays the role of the *driver intermediary*.

Our paper contributes to the literature by identifying the presence of driver intermediaries in the functioning of the QH model. In other words, the complexity to transit from one type of energy to another requires that some agent leads the efforts by providing clear strategies, support and training and the utilisation of an intermediate energy element to reach a successful and smooth energy transition.

As stated before, we observed that both countries share similar climate control actions in order to boost energy transition. However, the implementation differs in Germany concerning the Netherlands. In figure 2.5 we summarised the main practices of each country by each member of the quadruple helix.

Despite the good climate results in Germany and the Netherlands, and the apparent success of the QH model in the transfer of knowledge and technology to impulse the energy transition, both countries recognise that renewables are not ready yet to take over fossil sources completely. In this sense, we identify that both countries have utilised a common energy transition element, which is the Natural Gas in order to compensate for the existing gap between their energy consumption and renewable production.

	Germany	Netherlands
Government	• The federal government set the rules and gives positive or negative incentives depending on the kind of energy used, fomenting the rise of <i>Green Industries</i>. • Also drives the entrepreneurship of the society with subsidies to <i>Green cooperatives</i>. • Impulse the use of Natural Gas as the intermediate step for the energy transition.	• It is a facilitator that set the legal framework, both federal and local in order to reach a smooth transition. • It relies heavily on the academy for the implementation of its policies. • They promote the use of natural gas as the bridge from fossil to renewables by being part of climate control initiatives and adopting academic research findings.
Industry	• Industry activities rely on government incentives, or taxes, for using, or not, a different kind of energy. • Strong focus on financial numbers (NPV) of Green projects. • Take advantages of subsidies, especially on natural gas to adopt in a faster way alternative energies	• It is characterised by the fast adoption of new renewables technology • Since the Netherlands do not produce fossil fuels, the collaboration between the industry and academy is close for the adoption of new technologies. • Create synergies between government policies and academy research to implement them as fast as possible. • Uses natural gas instead of oil and coal to reduce cost and complying with federal and local regulations.
Academy	• The academy performs the activities of a broker through technology transfer offices. • It is focused more on research that speeds up new green technologies than coordinating efforts among QH members to reach a successful energy transition. Have a long term vision.	• It takes the lead of driving the ET by supporting federal and local energy policies implementation. • The academy shares new renewable research findings to the industry, and it drives the creation of <i>Green entrepreneurs</i> among society. • It develops an educational system that is proactive in the use of renewables. • Strong focus on obtaining a properly phased transition, moving towards renewables by using NG as a transition element.
Society	• Society participation relies on government support, i.e., subsidies and taxes that lead to the consumption of clean energy. • It establishes green cooperation to adopt green energy via the government's intervention.	• It uses new energies if they are properly communicated. Such communication mainly comes from the academy. • Given the education system, society believes in creating the world of tomorrow with everyday actions.

Table 2.5: Comparison of QH members actions

Chapter 3

Government: The Driver Intermediary

3.1 Introduction

Energy plays a central role in the improvement of living standards and the generation of economic development because industries require it to transform inputs into products, and the society uses it to develop necessary and recreational activities (Royal-Dutch-Shell, 2018b). Consequently, the demand for energy presents an increasing trend due to population growth, technological changes, as well as the emerging of urban areas. Until now, such demand is satisfied employing fossil fuels, with a negative impact on climate conditions. Fossil fuels produce Green House Emissions (GHE), which have increased the world average temperature; the global community has experienced extreme temperatures with a consequent loss of biodiversity, hunger, and water crises (Hansen et al., 2010).

Overall, climate change negatively impacts on social welfare, which leads governments to control it by reducing GHE. The Kyoto Protocol (Wigley, 1998) and the Paris Agreement, signed during the 21st Conference of Parties (Dimitrov, 2016),

summarize international efforts to establish a global agenda that stabilizes greenhouse emissions. In such agreements, governments recognize the necessity to implement strategies that substitute fossil fuel energy by renewable energy, which is characterized by low, or even null, emission of greenhouses. From now on, to avoid confusion we previous transition periods, Energy Transition (ET) refers to a process of change in energy supply and demand on which fossil energies are being replaced by renewable energies such as solar, wind and geothermal (Rojey, 2009). Hence, this process involves the society and industries as well as governments (Leach, 1992). However, the success of the ET problem is compromised by the fact that producing renewable energy is too high, which harms its profitability, and consequently, the current production of renewable energy is not enough to cover the energy demand (Royal-Dutch-Shell, 2018c). Thus, it is necessary a “driver intermediary” that boost the adoption and consumption of renewable energies (Matschoss and Heiskanen, 2017).

We can understand the ET process as a phenomenon that implies the adoption and generation of new technologies. The innovation literature points out that the success of this process depends on the interactions among all economic agents; for example, the triple helix framework emphasizes on the importance between industry, academia, and government, while the quadruple helix adds the interaction with civil society. Our modeling approach basis on the fact that collaboration among the previous agents effectively deals with socioeconomic problems and is essential for faster adoption of new technologies (Lawrence et al., 2002). Although the academy also plays a central role in the development of more efficient energy production processes, in this paper, we do not analyze the impact of its interaction since we observe that consumption and production patterns in the energy market are changing in a plodding speed despite the advantages pointed out by the academic community (Samuel, 2003).

The main problem to reach a successful energy transition relies on the fact that renewable energy is not profitable for producers and not affordable for consumers. So, firms do not have incentives to change their production plans, and consumer prefers still consuming non-renewable energy. In this paper, we develop a game-theoretical framework to analyze the Government's roles in this energy transition. To reach this goal, the Government has a large variety of public policies to promote the energy transition: taxes/subsidies on consumption and production, investment on technological development, and direct intervention via public enterprises. The utilization of renewable energy is the ET's ultimate goal, and it can be interpreted as a technological change by the Triple Helix model.

Etzkowitz and Leydesdorff introduced the triple helix model in 2000, such model pursues the knowledge transference among Society, Industry, and Government to reach objectives that require the active participation of these agents. In the case of energy transition processes, Suarez and Gibaja (2019) point out the importance of establishing a driver intermediary that enhances the participation of all agents in the triple helix model. They compare ET's strategies in Germany and the Netherlands, leading countries in such process, and observe the existence of a driver intermediary on both countries to increase the use of renewable energy. In Germany, they find that the Government acts as the drive intermediary through public policy (Yawson, 2009), while the academia is the driver intermediary in the Netherlands since it focuses in designing academic programs that pursue ET's objectives. So, in this paper, we set the Government as the driver intermediary in a triple helix model that pursues energy transition. By modeling such interaction as a game, we show how Government intervention (through subsidies and taxes) can modify people's consumption and industry production structure. As Bill Gates pointed out, the ET process is not a zero-sum game; it requires that players build, debate, agree and create synergies to generate the best possible strategies that generate the higher

possible payoffs during the transition process (Aoki, 1984).

Our paper is closely related to Van Beurden (2017), and Bridge et al. (2013) the emphasize in the necessity of a driver intermediary that boosts the ET process. These authors indicate that an immediate change of fossil fuels to renewable energies is neither operationally or economically feasible given that technology to produce renewable energy is not geographically or economically available for everyone. Hence, we analyze how positive and negative incentives, imposed by the Government, can enhance the production and consumption of clean energy.

The paper is organized as follows. In section 2, we present the literature review that provides the reader with a better understanding of the ET process and the strategies that are used to reach it. Section 3 presents a game theoretical model for the energy transition process. Section 4 discusses the game's solution and its implications for public policy development. Finally, section 5 presents the conclusions of our work.

3.2 Literature Review

Renewable energies are also known as the "Golden Energies," given the positive externalities that they generate. Besides being considered the ideal solution against climate change, they also bring benefits for industry and society via the investment on innovation and research development, that consequently generates environment-friendly firms and new jobs (Poltronieri, 2016).

Although the ET concept is relatively new in the literature, the humankind history summarizes phenomena that cast similarities with the adoption of renewable energy. In general terms, we can understand ET as a process in which societies substitute an energy source by others. In this sense, the first industrial revolution represents the transition from energy produced by wood to energy generated by coal

in the nations that experienced such revolution (Blinder, 2006). Also, the automobile invention boosted a transition from coal to oil (Nakicenovic, 1986).

Note that it is not clear how much time is necessary to substitute fossil energy by renewable energy. This process faces three central challenges: i. to maintain GHE under control, ii. to cover energy demand in a situation where population and urban areas (that concentrate a significant energy consumption share) present a continuous growth rate (British-Petroleum, 2018; Kemp et al., 2007). According to Hansen et al. (2010) given the social and environmental implications of climate change, governments and academicians agree to develop strategies that reach the transition from fossil energies to renewable energies as fast as possible in an organized manner with the collaboration between the industry, society and government (Torsten et al., 2017; Hua et al., 2016).

In the international community, we can observe that the state of the ET process varies across countries since it faces significant challenges. In other words, Rosenow et al. (2017) point out that developed countries present a significant advance in moving from oil energy consumption towards renewable energy, while nations, in the developing world, have problems to manage such transition due to high costs. In some countries, the adoption of renewable energy is difficult since their societies have just moved from coal to oil, and socioeconomic issues do not allow them to adopt technologies for producing clean energy (Sousa and Salavisa, 2014).

3.3 The Model

Note that energy production/consumption may refer to electricity, coal, or natural gas, namely energy commodities. Given that such commodities serve to develop different human activities, in this paper, energy refers to the force that consumers can entirely substitute regardless of the resources that producers use to generate it.

So, an "energy market" refers to the place in which consumers and producers trade this energy.

We know that the ET process pursues the consumption and production of energy generated by renewable resources (sunlight, wind, etc.), instead of energy produced by non-renewable resources (coal and oil). In the spirit of the triple helix model, we model the interactions within the energy market between consumers, producers, and the Government.

3.3.1 Basics of the model

To simplify the model, we assume that the producer uses two resources to generate energy, one is a renewable resource (r), and the other is a non-renewable (f). So, $\mathcal{R} = \{r, f\}$ is the set of all energy resources, and we use ρ to denote a generic energy resource. From now on, we say that energy is renewable, or not when it is produced by using the renewable resource, or the other resource.

There is a representative consumer $\mathcal{C}$ that consumes a quantity of energy Q , and distinguishes if the energy is produced by one resource or the other. Let Q^ρ be the energy produced by using ρ that $\mathcal{C}$ demands. Hence, the total demand of $\mathcal{C}$ is $Q = Q^r + Q^f$, where (Q^r, Q^f) is a consumption bundle for her. The set of all possible consumption bundles is $\mathcal{B} = \{(Q^r, Q^f) \in \mathbb{R}^2 | Q^r, Q^f \geq 0\}$. The consumer's preferences are represented by a utility $u_{\mathcal{C}} : \mathcal{B} \rightarrow \mathbb{R}$. Also, $\mathcal{C}$ has an amount of money $\omega > 0$ that she uses to buy energy bundles.

Concerning the supply side, we know that energy production is no longer exclusive of public monopolies since governments also pursue to guarantee energy accessibility and demand. So, we consider $\mathcal{F} = \{1, 2, \dots, n\}$ as the set of all energy producers (public or private), where i denotes a generic producer in $\mathcal{F}$. We assume that each producer i produces energy by using all resources in $\mathcal{R}$; let q_i^ρ be the energy that i produces by using the resource ρ . The total quantity of energy that

i produces is $q_i = q_i^r + q_i^f$, hence, we have say that $\bar{q}_i = (q_i^r, q_i^f)$ is a production plan of i . Let Y_i be the set of all production plans $\bar{q}_i$ of firm i , i.e., Y_i is the set of production possibilities and note that $Y_i \subset \mathbb{R}_+^2$. So, the total energy produced by using the resource ρ is $q^\rho = \sum_{i=1}^n q_i^\rho$.

The production cost is a function $c_i : Y_i \rightarrow \mathbb{R}$, i.e. $c_i(q_i^r, q_i^f)$ is the cost of producing the plan (q_i^r, q_i^f) . We assume that costs are separable, i.e, there exists costs functions c_i^r, c_i^f such that $c_i(q_i^r, q_i^f) = c_i^r(q_i^r) + c_i^f(q_i^f)$. Murray et al. (2012) points out that renewable energy has increasing production costs since f is scarce and difficult to get, i.e., we consider that $dc_i^f/dq_i^f > 0$. Concerning renewable energy, its production requires new technologies that implies a significant sunk cost, mainly a large initial investment; however, the literature agrees that such energy has constant marginal costs (Van Beurden, 2016; Bridge et al., 2013). Thus, we consider that $dc_i^r/dq_i^r = k$, where k is a constant larger or equal to zero.

Let g be the government. We assume that g is the driver intermediary of the ET process, which means that it is in charge of boosting the consumption and production of renewable energy via public policy. The literature identifies that taxes (on non-renewable energy consumption) and subsidies (on firms' production costs) have a positive impact on accelerating the ET process (Yoshino and Taghizadeh-Hesary, 2018; Ito, 2017). Hence, an ET's public policy is a vector $\bar{p} = (\tau, \sigma)$ such that τ is a quantity tax on consumption Q^f and σ is a direct subsidy to production costs c_i^r . The set of all ET's policy strategies is $\mathcal{P} = \{(\tau, \sigma) \in \mathbb{R}^2 | \tau, \sigma \geq 0\}$. Finally, the government measures the impact of a public policy $\bar{p}$ through a welfare function $W : \mathcal{P} \rightarrow \mathbb{R}$.

3.3.2 The energy transition game

Before to describe the game, remember that energy markets characterize by an oligopoly's competition, which means that firms in $\mathcal{F}$ have market power; i.e., $\mathcal{C}$

does not follow a strategic behavior. Thus, the consumer determines the demand for energy, which is of common knowledge by the Government and firms. So, the strategic interaction happens between the Government and all firms because firms have market power and the Government intervenes. In other words, the set of players is $\mathcal{P} = \{g\} \cup \mathcal{F}$.

We model the ET process as a three-stages game, in which the government defines a public policy (τ, σ) , in stage 1, that implements in the next two stages. Let $\mathcal{T} = \{1, 2, 3\}$ the set of game's stages, where t is a generic stage. So, (q_i^{tr}, q_i^{tf}) denotes the production plan of firm i at stage t , for $t \in \{2, 3\}$. Formally, the game unfolds as follows:

Stage 1. The government g sets a public policy $\bar{p} = (\tau, \sigma)$ such that τ is a quantity tax on the consumption of non-renewable energy and σ is a direct subsidy to diminish the production costs of renewable energy.

Stage 2. Consumers and producers observe the public policy, and the government implements the quantity tax τ to the consumption on non-renewable energy. All firms in $\mathcal{F}$ observe the demand for energy and determine their production plan. In other words, firms simultaneously choose a production plan $q_i^2 = (q_i^{2r}, q_i^{2f}) \in Y_i$ for all $i \in \mathcal{F}$.

Stage 3. The Government allocates a subsidy σ for the production of renewable energy to every firm i . As in the previous stage, all firms compete in quantities by simultaneously choosing a production plan $(q_i^{3r}, q_i^{3f}) \in Y_i$ for all $i \in \mathcal{F}$.

We model the ET process as the result of a three-stage game. The first stage refers to the government design of public policy, i.e., it is the leader of this process since we define it as the driver intermediary. In the second stage, the Government imposes a quantity tax to the consumption of non-renewable energy and energy producers compete in quantities. The third and final stage summarizes a Cournot competition when the Government provides subsidies to renewable production.

3.4 Market features

Before to compute the game's solution, in this section we introduce the assumptions that we need to capture the energy process. Also, based on these features, we describe the payoffs that triple helix agents get when the game finishes.

3.4.1 The energy demand

Before to describe the players' payoffs, we first discuss the features of the energy market. The definition of energy that we consider establishes that energy is any resource that $\mathcal{C}$ uses to develop her activities. So, it is reasonable to assume that $\mathcal{C}$ does not distinguish between renewable and non-renewable energy since both energies serve $\mathcal{C}$ to develop the same activities. Hence, we can assume that consumers have perfect substitutes preferences concerning energy; they do not distinguish if the energy is produced by using renewable or non-renewable fuels.

Assumption 1. $\mathcal{C}$ has perfect substitutes preferences, i.e., we consider that

$$u_{\mathcal{C}}(Q^r, Q^f) = a_r Q^r + a_f Q^f,$$

where a_r, a_f are positive constants.

Let ω^t and p_{ρ}^t the consumer's wealth and the price of the energy produced by using ρ , respectively, for all $t \in \{2, 3\}$. We assume that $\omega^t = \omega$. Given that $\mathcal{C}$ does not follow a strategic behavior and she has perfect substitutes preferences, her demand on each stage depends on how large is the relative price p_r^t/p_f^t in comparison with the substitution rate a_r/a_f (see Assumption 1).

Assumption 2. The relationship between relative prices and the substitution rate is as follows

a. In the second stage, we have that

$$\frac{p_r^2}{p_f^2 + \tau} > \frac{a_r}{a_f}$$

b. During the second stage, we have that

$$\frac{p_r^3}{p_f^3 + \tau} < \frac{a_r}{a_f}.$$

Assumption 2 establishes that $\mathcal{C}$ prefers to consume non-renewable energy in the first stage, which is an appealing assumption to analyze the current state of the ET process in emerging economies. Also, Assumption 2 considers the opposite for the second stage; in other words, the energy transition is reached during the second stage.

Let $p^t(Q^t)$ be the inverse demand of energy at stage $t = 2, 3$. Also, consider that $p^t(Q^t) = p_r^t(q_r^t) + p_f(q_f^t)$, where $p_\rho^t(q_\rho^t)$ is the inverse demand of energy produced by ρ at stage t .

By Assumptions 1 and 2, consumer $\mathcal{C}$ only demands non-renewable energy during the second stage of the transition process. In the third stage, non-renewable energy is perfectly substituted by renewable energy. Consequently, the demand of energy is as follows

$$Q^2 = Q_f^2 = \frac{\omega}{p_f^2 + \tau} \quad \text{and} \quad Q^3 = Q_r^3 = \frac{\omega}{p_r^3}. \quad (3.1)$$

From expression (3.1), producers face the following inverse demand of energy

$$p^2(Q^2) = p_f^2(Q_f^2) = \frac{\omega - \tau Q_f^2}{Q_f^2} \quad \text{and} \quad p^3(Q^3) = p_r^3(Q_r^3) = \frac{\omega}{Q_r^3}. \quad (3.2)$$

In other words, $p^t(Q^t)$ is the inverse demand of energy at $t \in \{2, 3\}$.

3.4.2 Payoffs

To describe the total benefit that producers get at the end of the energy transition process, remember that g imposes a public policy (τ, σ) . The government's policy pursues that $\mathcal{C}$ totally substitutes her consumption of non-renewable energy, during the first stage, by consumption of renewable energy, in the second stage (see expression (3.1)). So, g applies a tax τ on the consumption of non-renewable energy in

the second stage, where firm i gets the following benefit

$$\pi_i^2(q^2, \tau, \sigma) = \left(\frac{\omega - \tau Q_f^2}{Q_f^2} \right) q_i^{2f} - c_i^f(q_i^{2f}). \quad (3.3)$$

Also, g provides a subsidy for the production of renewable energy during the third stage. Thus, the benefit of i during the third stage is

$$\pi_i^3(q^3, \tau, \sigma) = \left(\frac{\omega}{Q_r^3} \right) q_i^{3r} + \sigma q_i^{3r} - c_i^r(q_i^{3r}). \quad (3.4)$$

Finally, we assume that firms have a discount rate $\delta \in (0, 1)$ that represents their valuation between producing at stage two, the current situation, and producing during stage three, the scenario where energy transition has been reached. Therefore, the present benefit that producer i gains when the game finishes is

$$\pi_i(q^2, q^3, \sigma, \tau) = \pi_i^2(q^2, q^3, \sigma, \tau) + \delta \pi_i^3(q^2, q^3, \sigma, \tau).$$

Concerning the government, note that its payoff is the society's welfare during the whole energy transition process. Hence, it is necessary to describe the consumer's utility when the ET process finishes. Notice that we consider a non-strategic consumer, i.e., she demands an energy consumption bundle that maximizes her utility, restricted to her budget constraints, in a duopoly market. In other words, $\mathcal{C}$ consumes the energy that the duopoly market generates at each stage of the ET process. By considering a discount rate $\delta_{\mathcal{C}} \in (0, 1)$, the present value of consumer's utility is

$$U_{\mathcal{C}}(Q^2, Q^3) = u_{\mathcal{C}}(Q^2) + \delta_{\mathcal{C}} u_{\mathcal{C}}(Q^3).$$

Since $\mathcal{C}$ has perfect substitutes preferences, we have that

$$U_{\mathcal{C}}(Q^2, Q^3; \tau, \sigma) = \frac{a_f \omega}{p_f^2(Q_f^2)} + \delta_{\mathcal{C}} \frac{a_r \omega}{p_r^3(Q_r^3)}. \quad (3.5)$$

Now, we are ready to describe the government's payoff. As we mentioned before, g measures the impact of a public policy (τ, σ) on society's welfare, which is function

from the set of all possible vectors (τ, σ, Q^2, Q^3) to $\mathbb{R}$. We consider that g has a utilitarian welfare function W , which means that the total welfare is the sum of firms' benefits and consumer's utility. So, we have that

$$W(\tau, \sigma, Q^2, Q^3) = \sum_{i=1}^2 \pi_i(q^2, q^3, \sigma, \tau) + U_C(q^2, q^3, \sigma, \tau). \quad (3.6)$$

3.5 Equilibrium Analysis

In Section 3 we consider that firms 1 and 2, together with the government g interact in a three-stage game. Hence, we consider the Sub-game Perfect Nash equilibrium as the solution concept of the energy transition game. We need to introduce some extra notation to set the solution concept.

Due to energy producers make decisions in the second and third stages, a firm i strategy is a vector $s_i = (q_i^2, q_i^3) = (q_i^{2f}, q_i^{2r}, q_i^{3f}, q_i^{3r})$ that indicates the quantity of renewable and non-renewable energy that i produces during the ET process. Let S_i be the set of all possible strategies s_i . Concerning the government, it makes decisions only in the game's stage i.e., a strategy of g is a public policy vector $s_g = (\tau, \sigma)$. We denote by S_g the set of all possible strategies s_g . A strategies profiles is a vector $s = (s_1, s_2, s_g) \in S_1 \times S_2 \times S_g$.

Definition 3. Let $s^* = (s_1^*, s_2^*, s_g^*) = (q_1^{2*}, q_1^{3*}, q_2^{2*}, q_2^{3*}, s_g^*)$ a strategy profile in $S_1 \times S_2 \times S_g$. We say that s^* is a Sub-game perfect Nash equilibrium if it induces a Nash equilibrium at each stage of the game, that is to say

- a. $W_g(s_1^*, s_2^*, s_g^*) \geq W_g(s_i^*, s_j^*, s_g)$ for all $s_g \in S_g$,
- b. $\pi_i(q_i^{2*}, q_i^{3*}, s_j^*, s_g^*) \geq \pi_i(q_i^2, q_i^{3*}, s_j^*, s_g^*)$ for all $s_i = q_i^2, q_i^{3*} \in S_i$, $i, j \in \mathcal{F}$, and
- c. $\pi_i(q_i^{2*}, q_i^{3*}, s_j^*, s_g^*) \geq \pi_i(q_i^{2*}, q_i^3, s_j^*, s_g^*)$ for all $s_i = q_i^{2*}, q_i^3 \in S_i$, $i, j \in \mathcal{F}$.

In the following subsection we compute the set of the Sub-game perfect Nash equilibria of the ET game. Since we have a three-stage game, we proceed by backward induction.

3.5.1 Third stage analysis

To find the firms' equilibrium strategies in the ET game, we first compute the set of Nash equilibria of the third stage. So, firms 1 and 2 assume that they choose production vectors q_1^2 and q_2^2 , respectively, during the second stage, while the government sets a public policy (τ, σ) at the first stage. So, during the last stage, energy producer i chooses a vector q_i^3 that maximizes its benefit $\pi_i(q^1, q^2, \tau, \sigma)$.

We know that consumer $\mathcal{C}$ does not demand fossil energy at stage 3 because she has perfect substitutes preferences (see Assumption 1) and the government searches for completing the ET process in the third stage (see Assumption 2). Then, renewable energy does not generate positive benefits for all $i \in \mathcal{F}$, which implies that

$$q_1^{3f} = q_2^{3f} = 0.$$

Also, Assumption 2 implies that Q^3 , that total energy production at stage 3, is independent of the energy production at stage 2, the quantity Q^2 , because consumers have successfully substituted non-renewable energy by renewable energy when the game finishes. Consequently, the benefit π_i^2 does not depend on (q_i^3, q_j^3) , i.e., the benefit that firms get at the end of the second stage is constant in the following stage.

By the previous discussion, we can compute the Nash equilibria of Stage 3 by focusing on the benefit π_i^3 and decision variable q_i^{3r} , for all $i \in \mathcal{F}$. In words, if j produces q_j^{3r} , q_i^{2r} is a best response for i if it solves the following optimization problem

$$\max_{q_i^{3r} \in \mathbb{R}} \pi_i^3(0, q_i^{3r}, 0, q_j^{3r}; q_i^2, q_j^2, \tau, \sigma), \quad (3.7)$$

where

$$\pi_i^3(0, q_i^{3r}, 0, q_j^{3r}, \tau, \sigma) = \frac{\omega}{q_i^{3r} + q_j^{3r}} q_i^{3r} + \sigma q_i^{3r} - c_r q_i^{3r}.$$

By the first order condition criterion, a best response of i to production q_j^{3r} is a solution of the equation $\partial \pi_i^3 / \partial q_i^{3r} = 0$. Then, we have that

$$\begin{aligned} 0 &= \frac{\partial \pi_i^3}{\partial q_i^{3r}} \\ &= \frac{\omega (q_i^{3r} + q_j^{3r}) - \omega q_i^{3r}}{(q_i^{3r} + q_j^{3r})^2} + \sigma - c_r \\ &= \frac{\omega q_j^{3r}}{(q_i^{3r} + q_j^{3r})^2} + \sigma - c_r. \end{aligned}$$

The previous expression can be rewritten as follows

$$\frac{\omega q_j^{3r}}{(q_i^{3r} + q_j^{3r})^2} = c_r - \sigma,$$

which we solve to find the best response of i to any renewable energy production of j during. So, we have that

$$\begin{aligned} (c_r - \sigma) (q_i^{3r} + q_j^{3r})^2 &= \omega q_j^{3r} \\ (q_i^{3r} + q_j^{3r})^2 &= \frac{\omega q_j^{3r}}{c_r - \sigma} \\ q_i^{3r} + q_j^{3r} &= \sqrt{\frac{\omega q_j^{3r}}{c_r - \sigma}}. \end{aligned}$$

So, the best response of i to q_j^{3r} is

$$q_i^{3r}(q_j^{3r}) = \sqrt{\frac{\omega q_j^{3r}}{c_r - \sigma}} - q_j^{3r}, \quad (3.8)$$

for all $i, j \in \mathcal{F}$. Then, to compute the Nash equilibrium of the third stage we need

to solve the fixed point equation $q_i^{3r} = q_i^{3r}(q_i^{3r})$, which implies that

$$\begin{aligned} q_i^{3r} &= \sqrt{\frac{\omega}{c_r - \sigma} \left(\sqrt{\frac{\omega q_i^{3r}}{c_r - \sigma}} - q_i^{3r} \right)} - \left(\sqrt{\frac{\omega q_i^{3r}}{c_r - \sigma}} - q_i^{3r} \right) \\ 0 &= \sqrt{\frac{\omega}{c_r - \sigma} \left(\sqrt{\frac{\omega q_i^{3r}}{c_r - \sigma}} - q_i^{3r} \right)} - \sqrt{\frac{\omega q_i^{3r}}{c_r - \sigma}} \\ \sqrt{\frac{\omega q_i^{3r}}{c_r - \sigma}} &= \sqrt{\frac{\omega}{c_r - \sigma} \left(\sqrt{\frac{\omega q_i^{3r}}{c_r - \sigma}} - q_i^{3r} \right)} \end{aligned}$$

To solve the previous equation for q_i^{3r} , we square both its sides

$$\frac{\omega q_i^{3r}}{c_r - \sigma} = \frac{\omega}{c_r - \sigma} \left(\sqrt{\frac{\omega q_i^{3r}}{c_r - \sigma}} - q_i^{3r} \right)$$

Since $\omega \neq 0$ and σ is a subsidy for the production quantity, $\sigma \in (0, 1)$, we consider that $c_r \neq \sigma$. Thus, we get

$$\begin{aligned} q_i^{3r} &= \sqrt{\frac{\omega q_i^{3r}}{c_r - \sigma}} - q_i^{3r} \\ 2q_i^{3r} &= \sqrt{\frac{\omega q_i^{3r}}{c_r - \sigma}}. \end{aligned}$$

Therefore, at equilibrium, the renewable production for i is

$$q_i^{3r} = \frac{\omega}{4(c_r - \sigma)} \text{ for all } i \in \mathcal{F}. \quad (3.9)$$

The following proposition presents the equilibrium's profile of energy production at stage 3, which summarizes the above discussion.

Proposition 4. *The Nash equilibrium of the third stage is the production strategies profile $q^{3*} = (q_1^{3*}, q_2^{3*})$ where*

$$q_i^{3*} = \left(q_i^{3f*}, q_i^{3r*} \right) = \left(0, \frac{\omega}{4(c_r - \sigma)} \right),$$

for all $i \in \mathcal{F}$.

Proposition 4 indicates that the Nash equilibrium of the third stage is unique, a situation that allows us to perform some natural comparative statics. Particularly, we establish the relationship between the production of renewable energy concerning the productions costs (c_r) and the government's subsidy (σ).

Aside the behavior of energy producers at equilibrium, it is worth mentioning the market price.

Proposition 5. *The equilibrium's price of renewable energy is*

$$p_r = 2(c_r - \sigma).$$

Proof. We know that $\mathcal{C}$ has perfect substitute preferences. Since we consider that the energy market successfully reaches the energy transition in the third stage, the inverse demand for renewable energy is given by

$$p_r(Q_r^3) = \frac{\omega}{Q_r^3},$$

see expression (3.2). Also, the total production of renewable energy is

$$Q_r^3 = \frac{\omega}{2(c_r - \sigma)}$$

at equilibrium. By substituting the previous quantity into the demand of renewable energy, we get that

$$\begin{aligned} p_r\left(\frac{\omega}{2(c_r - \sigma)}\right) &= \frac{\omega}{\omega/(2(c_r - \sigma))} \\ &= 2(c_r - \sigma). \end{aligned}$$

□

Proposition 6. *Consider the three-stage ET game describe in section 2. In the third stage, the equilibrium's renewable production has a positive relationship concerning the government's subsidy and consumer's wealth, and it has negative relationship with respect to the production cost.*

Proof. By Proposition 4, the equilibrium's quantity of renewable energy is $q_i^{3r*} = \omega/(4(c_r - \sigma))$. To determine the relationship between q_i^{3r} and ω , σ , and c_r , we take the derivative of the equilibrium's production concerning these exogenous variables. Thus, we have that

$$\begin{aligned}\frac{\partial q_i^{3r}}{\partial \omega} &= \frac{1}{4(c_r - \sigma)} > 0, \\ \frac{\partial q_i^{3r}}{\partial \sigma} &= \frac{\omega}{16(c_r - \sigma)^2} > 0, \\ \frac{\partial q_i^{3r}}{\partial c_r} &= -\frac{\omega}{16(c_r - \sigma)^2} < 0.\end{aligned}$$

So, the equilibrium's production of renewable energy has positive relationship with ω and σ . Also, there is a negative relationship between q_i^{3r*} and c_r . $\square$

In words, the previous proposition indicates that production of renewable energy increases as consumer's wealth and government's subsidy increases. Also, we have that energy producer diminish the production of renewable energy whenever its production cost increases.

3.5.2 Second stage analysis

Now, we compute the production strategies at equilibrium for energy producers in the second stage. Thus, we substitute the Nash equilibrium of the third stage q^{3*} , as it is presented in Proposition 4, into the total benefit function $\pi_i(q^2, q^3, \tau, \sigma) = \pi_i^2(q^2, q^3, \tau, \sigma) + \pi_i^3(q^2, q^3, \tau, \sigma)$ of each producer i . Also, we consider that the public policy (τ, σ) is exogenous.

It is important to recall that consumer $\mathcal{C}$ has perfect substitutes preferences and g establishes a public policy to transition from fossil energy consumption to renewable consumption. So, the second stage of the ET game represents a scenario where no renewable energy is demanded, which implies that it is not profitable for energy producers to generate renewable energy during this stage. Consequently,

energy producer do not generate renewable energy during stage 2, and $q_i^{2r} = 0$ for all $i = 1, 2$. By Assumption 2, we have that benefit π_i^2 is independent from the production (q_i^{3f}, q_i^{3r}) carry out during the third stage; even more, the benefit π_i^3 is also independent from production actions (q_i^{2f}, q_i^{2r}) at stage 2. In other words, π_i^3 is constant during the second stage, which allows us to focus on analyzing π_i^2 to compute the equilibrium strategies of each $i \in \mathcal{F}$. Then, a best response of i to any action q_j^{2f} is a solution of the following optimization problem

$$\max_{q_i^{2f} \in \mathbb{R}} \pi_i^2(q_i^{3*}, q_j^{3*}, q_i^{2f}, 0, q_j^{2f}, 0; \tau, \sigma), \text{ for all } i \in \mathcal{F}, \quad (3.10)$$

where

$$\pi_i^2(q_i^{2f}, 0, q_j^{2f}, 0, q^{3*}; \tau, \sigma) = \left(\frac{\omega - \tau (q_i^{2f} + q_j^{2f})}{q_i^{2f} + q_j^{2f}} \right) q_i^{2f} - c_f q_i^{2f}.$$

Note that we can rewrite the benefit function π_i^2 in the following way

$$\pi_i^2(q_i^{2f}, 0, q_j^{2f}, 0, q^{3*}; \tau, \sigma) = \left(\frac{\omega}{q_i^{2f} + q_j^{2f}} - \omega \right) q_i^{2f} - c_f q_i^{2f} = \frac{\omega q_i^{2f}}{q_i^{2f} + q_j^{2f}} - \omega q_i^{2f} - c_f q_i^{2f}.$$

By the first order condition, a best response of i to any q_j^{2f} is the solution of the equation $\partial \pi_i^2 / \partial q_i^{2f} = 0$; thus, we have that

$$\begin{aligned} 0 &= \frac{\omega(q_i^{2f} + q_j^{2f}) - \omega - \omega q_i^{2f}}{(q_i^{2f} + q_j^{2f})^2} - \tau - c_f \\ &= \frac{\omega q_j^{2f}}{(q_i^{2f} + q_j^{2f})^2} - \tau - c_f. \end{aligned}$$

The previous expression implies that

$$\begin{aligned} (\tau + c_f) (q_i^{2f} + q_j^{2f})^2 &= \omega q_i^{2f} \\ (q_i^{2f} + q_j^{2f})^2 &= \frac{\omega q_i^{2f}}{\tau + c_f} \\ q_i^{2f} + q_j^{2f} &= \sqrt{\frac{\omega q_i^{2f}}{\tau + c_f}}. \end{aligned}$$

By the previous expression, we conclude that the best response of i to any production q_j^{2f} is given by

$$q_i^{2f}(q_j^{2f}) = \sqrt{\frac{\omega q_i^{2f}}{\tau + c_f}} - q_j^{2f}, \quad (3.11)$$

for all $i, j \in \mathcal{F}$.

To compute the Nash equilibrium of the third stage, we solve the fixed point equation $q_i^{2f} = q_i^{2f}(q_j^{2f}(q_i^{2f}))$, whose solution follows an analogous calculation than the one illustrated in Proposition 4; the next proposition summarizes this discussion.

Proposition 7. *The Nash equilibrium of the second stage is the production strategies profile $q^{2*} = (q_1^{2*}, q_2^{2*})$ where*

$$q_i^{2*} = \left(q_i^{2f*}, q_i^{2r*} \right) = \left(\frac{\omega}{4(c_r + \tau)}, 0 \right),$$

for all $i \in \mathcal{F}$.

3.5.3 First stage analysis

We consider that the government allocates subsidies among energy producers by using its gains of applying the quantity tax.

Assumption 8. *The government funds renewable energy subsidies through taxing non-renewable energy consumption, i.e.*

$$\sigma = \tau Q_1. \quad (3.12)$$

3.6 Conclusions

Our research concludes that a proper interaction of the quadruple-helix is needed to propel the energy transition to a successful end. However, in order to impulse the efficient function of the helix, and by this, changing the habits of consumers to

adopt in a faster manner renewable energy, one of the members needs to take the leadership of the helix, we have defined this position as the *Driver Intermediary*. In this case we have shown through a game theory approach that the Government is the one that must play that role by applying positive incentives, **subsidies**, to both of their consumers, the industry to impulse the production of renewable energy, and the society to promote the adoption of it; and by imposing negative incentives, **taxes**, so both of them will have an economic pressure to move away from fossil sources.

By defining the agent of the QH that should act as the *Driver Intermediary*, in future investigations we need to define what will be the *intermediate element* required in the ET process to reach a successful end.

Chapter 4

Natural Gas: The Transition Element

4.1 Introduction

The world is entering a period of high energy consumption, caused by the continuous population growth. Every day, a greater part of the global population is reaching a better standard of living by having access to electricity, drinking water, paved roads among other public services (Royal-Dutch-Shell, 2018b). Such life's improvement leads to an increase in energy consumption that is satisfied by fossil fuels with negative externalities like climate change, which affects the environment and threatens the sustainability of future societies (Hansen et al., 2010). Most governments around the world have joined efforts to control climate change through international agreements such as the Kyoto Protocol (UN, 1992) and the Paris Agreement (UN, 2016), where countries have committed to implement strategies to boost the successful Energy Transition (ET), that is to say, to take demand and supply of energy from the current point, where energy is mainly generated by fossil fuels, to a state in the future where the global energy needs are satisfied mostly by renewable energies

(UN, 2016).

They have also agreed that ET have to be properly planned and implemented in a disciplined manner, globally aligned to standard rules but adapt them individually according to each country idiosyncrasy and economic (Leach, 1992; Guidolin and Guseo, 2019).

In countries where the ET process is already taking place, i.e. Germany and the Netherlands, we observe that its success have depended on a gradual implementation of two main actions: one that involves the proper interaction of the so named quadruple-helix (government, industry, academia and society), in which one of them takes the role of the leader or also known as *Driver Intermediary*; and a second strategy referred to the inclusion of an intermediate energy element that serves as a *transition element* that builds a bridge between traditional fossil energy and renewables (EIA, 2016).

Based on the foregoing, Mexico has initiated the process of the ET through the so-called "Energy Reform" enacted in 2013. Opening its production and distribution market to private investors, both domestic and foreign (IEA, 2018a; Gobierno-De-Mexico, 2013).

In developing the bases of this reform, all four members of the quadruple-helix were consulted through participatory forums, however three of them (Industry, Academy and Society) were excluded during the elaboration of secondary laws and conducive regulations, which has caused that the ET implementation has not been as effective as expected (EIA, 2016).

Suarez and Gibaja (2019) in previous research have demonstrated that in Mexico is the government the responsible for assuming the leadership role in the implementation of the ET, acting as *the driver intermediary*. The purpose of this article is to perform an integral strategic analysis of the Natural Gas (NG) industry in Mexico to be considered as the transition element that drives the ET in the country.

This paper is presented in three sections beside the current introduction. The second section is a contextual framework in which we provide the reader a better understanding of the ET across the world and how the NG has become the preferred alternative energy to be the intermediate element that compensates the existing gap between the global energy demand and the renewable energy production. Also this section allows the reader to have a better perspective of the current state of the ET in Mexico; its legal framework and the future role of the NG in this transition. In the methodology explained the strategic analysis tools utilized to evaluate the NG as the potential transition element for the Mexican ET, giving way to the fourth section where the fore mentioned tools are implemented to analyze the NG industry in Mexico and the North American region, finally we present our conclusions.

4.2 Contextual Frame

4.2.1 Natural Gas

World's energy requirements are increasing every day hand to hand with the rate of population growth and the fact that every time a greater number of inhabitants is gaining access to better living standards, which we understand as getting access to public services leading to an increase in per capita energy consumption translating this as the central driver of climate change given that most of the current energy production is based on fossil fuels (Hansen et al., 2010).

Derived from this analysis, world leaders signed in 1992 the *Tokyo Protocol*, where they committed to reduce the emission of greenhouse emissions. Later, during the *Conference of Parties 21* (COP 21) in 2015, the *Paris agreement* was signed to ratifying Kyoto Protocol commitments with the inclusion of clear and quantifiable goals with the main target to maintain global warming below two degrees by 2050 (UN, 2016).

In recent years, based on the lessons learned from countries with a major advances in the process of the ET, it has become evident the need to use a transition element that allows a successful transition from the current massive use of fossil energy to mostly renewable. In these lessons, the NG have play a fundamental role, as it compensates oil and coal properties, it provides features that allows to substitute coal and oil, such as its combustion is cleaner than oil and coal (IEA, 2018a), moreover, based on empirical evidence the NG has demonstrated its contribution to climate change control by improving air quality (Hall, 2005). The Energy Protection Agency (EPA) in a 2002 study has affirmed that NG could be considered as one of the cleanest alternative fuels to be used in the ET.

In addition to the environmental advantages that NG represents, its industry is also a promoter of economic development. In the United States, for example, it is estimated that each job generated by the NG industry generates 2.7 additional jobs in related industries (British-Petroleum, 2018).

4.2.2 Energy Transition in the World

Europe

Europe is considered the *champion of the environmental protection* (European-Commission, 2015) in regions such as the Scandinavian and the Saxon countries, the ET is well advance and they are on target to comply with the Paris Agreement (UN, 2016) on time and in form. As Suárez and Gibaja (2019) have shown in their research, the proper functioning of the quadruple helix has become the key element for advancing successfully in the transition, as well as the use of an intermediary energy element that compensates the gap between the consumption required and the renewable production, in northern Europe the wind and the geo-thermal energy are emerging as the renewable source; in Germany and the Netherlands, both the wind and solar sources are growing; while in France is the nuclear energy, the com-

mon element among this regions is that the NG has been used as the intermediary element that builds the bridge which connects oil/coal consumption and renewables production (IEA, 2018a). 4.1 shows how the world is advancing with the ER, while 4.2 presents the advance of Europe's within the transition.

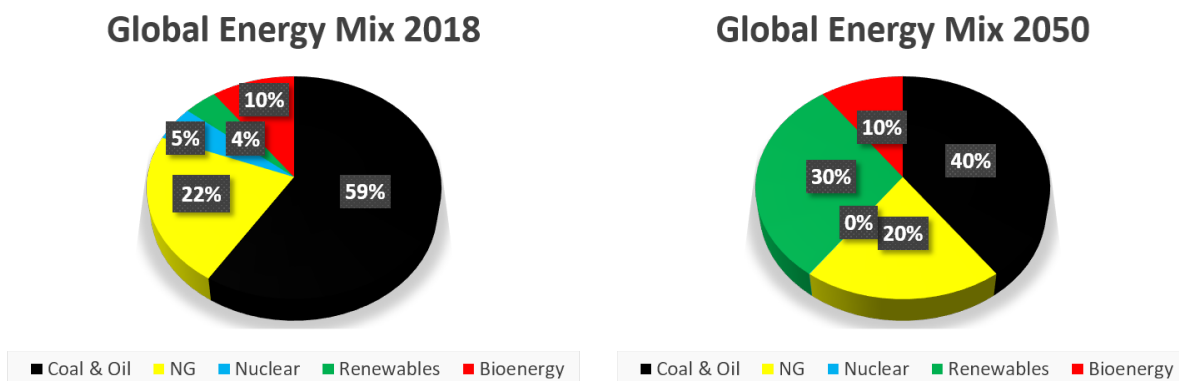


Figure 4.1: World current energy mix 2018 and 2050 forecasted mix (Own elaboration based on IEA (2018) data).

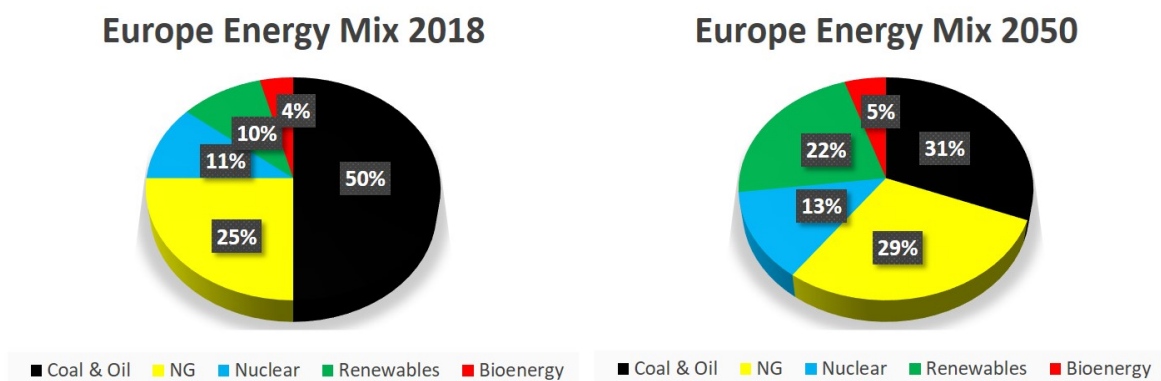


Figure 4.2: Europe current energy mix 2018 and 2050 forecasted mix (Own elaboration based on IEA (2018) data).

United States

While the US has become self-sufficient in energy production, mainly through fossil sources and the fracking technique, it is also experimenting an ET process. Society and Academy have been pushing Industry and the Government to move to more environment friendly energy sources (British-Petroleum, 2018). States such as California are imposing environmental taxes to fossil fuels use and giving incentives to users of renewables. An example of this is the price difference of fuel between California and Texas, where most of the fossil fuels reside. And that California has pushed to the car sharing industry (Uber, Cabify, etc.) to use hybrids or electric cars (IEA, 2018a).

Figure 4.3 shows how the ET in the US will advance in the fore coming years. Similarly than Central Europe, NG is being seen as the intermediary step between oil and renewables.

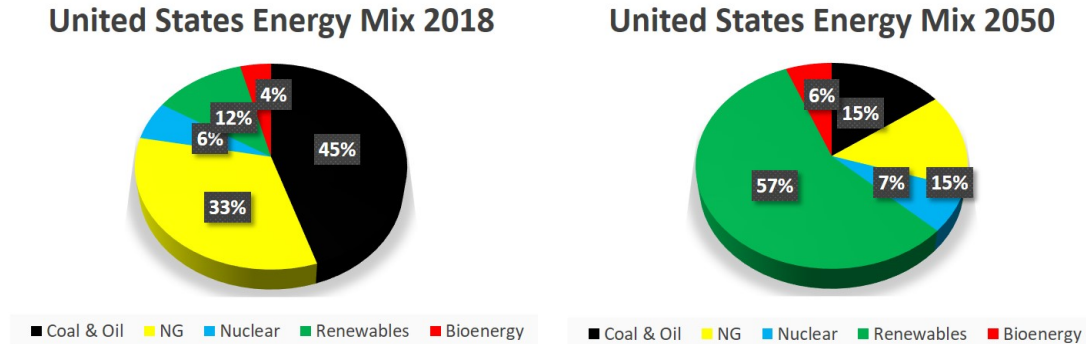


Figure 4.3: U.S. current energy mix 2018 and 2050 forecasted mix (Own elaboration based on IEA (2018) data).

4.2.3 Mexican Energy Transition

In 2013, when the Energy Reform (ER) (Gobierno-De-Mexico, 2013) and the Energy Transition law (Gobierno-De-México, 2015) were issued; the government established

an aggressive agenda towards reaching a successful ET, promoting the competitiveness within the Mexican energy market, as well as improving energy production and distribution processes. During the development of the ER, forums were carried on with scientists, academics, representatives of industry and society, following the example of leading countries, whose experience demonstrates that the interaction of the four helices of the technology transfer produces a more efficient adoption of renewable energies (Yawson, 2009).

Even though that strong efforts have been made to promote the ET, its implementation has not been consolidated yet. The National Hydrocarbons Commission, has stated that the unsuccessful implementation is a result of isolated initiatives and the lack of proper involvement of consumer requirements during the development of the secondary laws process. (CNH, 2018)

Legal framework for the energy transition in Mexico

From 1938 to 2018 Mexico was a monopoly market handled by the state company *PEMEX*, that served until 1994 as the main source of income for the country. It was in 2013 when the Mexican government approved the Energy Reform (Gobierno-De-Mexico, 2013), as the new legal tool that will promote an increase of competitiveness and a faster development of the Mexican energy market. Its fundamentals were based on the recognition that key country energy indicators were moving in the wrong direction of a modern Mexico, (IEA, 2018b). This reform opened the Mexican energy market to private investment, domestic and foreign, allowing a monopoly such as *PEMEX* to be able to benefit from global best practices of international energy companies by receiving financing and cutting-edge technology that will boost the activities of exploration and production of different sources of energy (Gobierno-De-Mexico, 2013), and substantially improving related areas such as storage, distribution and commercialization of energy.

Derived from the ER, the legislative branch developed its legal framework that would allow a proper implementation. A series of laws, norms and regulations were developed and independent public agencies were reinforced to supervise the faithful monitoring of the established legal framework; this is how the National Hydrocarbons Commission (CNH Comisión Nacional de Hidrocarburos) and the Energy Regulatory Commission (CRE – Comisión Reguladora de Energía) have emerged as sources of regulation in energy issues and, with the creation of the National Agency for Industrial Safety and Environmental Protection (ASEA – Agencia Nacional de Seguridad Industrial y de Protección del Ambiente) the environmental sustainability was taken into account by amendments in the Mexican Constitution.

Within the legal framework of the ER. The law of energy transition arisen to regulate the sustainable use of energy as well as the obligations in the field of developing renewable energy and the reduction of pollutants, without affecting the competitiveness of the Mexican productive sectors. The goal of the energy transition law is to reach by 2024 a 35% share of electricity generation sourced from clean energy (Gobierno-De-México, 2015). As mentioned, this law impulse the gradual increase of the participation of renewable energies in order to meet the national and international goals established in terms of reducing polluting emissions. As a summary, the ultimate goal of the ER reform is to pursue the reconfiguration of the hydrocarbon industry in Mexico by moving from a monopolistic structure, where the State was the unique agent with the ability to produce energy, to a perfect competence market that will speed up the adoption of clean technologies (CNH, 2018).

Current role of the natural gas in the mexican energy transition

Mexico has a privileged geographical position to boost the energy transition. The country is located in the North American region in which the production and con-

sumption of NG is experiencing a substantial growth (World energy outlook, 2018). Even when Mexico since 1995 has allowed in the natural gas market the participation of private companies for transportation, storage and distribution, has kept exploration and production in absolute control of Pemex. With the ER private companies are allowed to participate, in association with Pemex in the last two activities through direct assignments, contracts, authorizations or tenders (Gobierno-De-Mexico, 2013).

The ER foresees the NG as the natural transition element in Mexico for a successful ET, and visualize its development mainly through new residential developments and the increase of its share in the electricity production (Royal-Dutch-Shell, 2018c). During the last decade of the 20th century, Mexico was self-sufficient in terms of natural gas supply, only 3% of the required consumption was imported; however, by 2018 over 90% was imported, mostly coming from the United States (Royal-Dutch-Shell, 2018a); this change was derived of a switch in government priorities that have driven more strongly the oil production instead of the natural gas, as it is more profitable. But at the same time, in the south US and the Gulf region, NG production has become more efficient, less cost equal to more volume output, through the use of the fracking technique (British-Petroleum, 2018; IEA, 2018b).

The previous paragraph remarks the solid reason that supports the fundamental base of the ER: open the Mexican market to impulse its international competitiveness, especially within the NG industry by creating synergies with the south of the US (IEA, 2018a).

Perspectives of the natural gas in the mexican energy transition

The future of NG in Mexico depends of an ER implemented efficiently. Country negative trend in energy production, and the constantly increase in energy imports will cause the national energy balance deficit to explode. The IEA have stated that

is vital for Mexico to give enough time for the ER to mature (around 10 years) (IEA, 2018a), and then the energy balance in Mexico will present a surplus.

In 2013 the CNH carried out works to the development of the ER, in them it was estimated that for Mexico to be self-sufficient in the production of NG, this must be increased at a rate of 14% annually, an objective which is achievable only by allowing the injection of monetary resources and technology from large global energy companies (CNH, 2018; Gobierno-De-Mexico, 2013). If this assumption happens, the future rising role of natural gas in Mexico's energy mix will be facilitated by extensive infrastructure development, and the ready availability of relatively cheap gas via new pipelines coming from southern United States (IEA, 2018b).

4.3 Methodology

Our approach to this research was to perform an comprehensive strategic analysis using three different tools, which allowed us to conduct a deductive investigation. We began with the analysis of the energy cluster where Mexico is located, the north east of the country, the south east of the United States and the Gulf of Mexico utilizing the Porter's diamond; then we analyzed the potential and attractiveness of the NG industry in our country by using the five forces that shape the competitiveness, also by Michael Porter; and finally through the Boston Consulting group Matrix we analyzed and evaluated the current portfolio of Mexico's energy products and what role each energy product should play in order to advance in the ET. By using this methodological approach, we obtained an integral analysis of the NG to be considered the most viable energy element to achieve a successful energy transition in Mexico.

4.3.1 Cluster Diamond analysis

The first strategic tool used is the Porter’s cluster approach, understanding that a cluster is a geographic concentration of interconnected companies, specialized suppliers, service providers, firms in related industries, and associated institutions, like universities and trade associations (Porter, 1993). Particularly, we used the “Cluster Diamond” (Porter, 1998), which is a diamond-shaped framework that focuses on explaining why certain industries within a particular region are competitive in the international market, whereas others might not. There are four direct factors that define the context for growth and innovation and productivity, and two indirect aspects that either impulse or slow the competitiveness of a region. For purposes of this analysis, we have integrated the cluster formed by the combined region of Mexico and the United States, since wells or hydrocarbon reserves do not distinguish geographic borders. The factors are:

- Context of industry strategy and rivalry
- Factor conditions
- Demand conditions
- Related and supporting industries
- Government
- Chance

4.3.2 Five Forces that shape strategy

The second strategic tool that we used is the Porter’s five forces that shape strategy. With this analysis we evaluated the long-term potential that the NG industry in Mexico will have within the energy transition process. These forces determine the profitability of the industry and become one of the most important tools to design strategy formulation (Porter, 2008). The five forces are:

- Power of buyers

- Power of suppliers
- Threat of new competitors
- Current competitors
- Substitute products

4.3.3 Boston Consulting Group matrix

The last strategy tool used in this analysis is Boston Consulting Group Matrix. This analytical method has help us to decide which energy approach will be the best for the Mexican portfolio of energy products and to discern where it is necessary to invest, divest or abandon the case (Morrison and Wensley, 1991). The matrix is a diagram in which one of its axes represents the growth of the industry, in this case it is energy and the second axis is the relative market share within that industry. These two axes generate four quadrants and each type of energy is represented by a bubble, whose size represents the value of that type of energy. To define the growth of the industry, it is compared with the GDP of the country, that is, it is high growth if it is greater than that of the national economy. The four quadrants are known as:

- *Question mark* products, is in the first quadrant, products with a rapid growth market that makes them attractive from an industry standpoint, however the low market share, and thus a big investment required, raises the question if an investment or divestiture has to be made.

- The second quadrant is known as the *Stars products*, such products have a large market share in a fast growing industry offering excellent profits and growing opportunities, on these products is where companies relies to boost the overall future performance of the portfolio and to expect to make most of the profits for the upcoming years.

- *Dog products* are in the third sector they have a small market share in a low growing industry and can't produce enough income to be financially viable,

companies with these kind of products need to divest on them.

- And finally the last quadrant is known as the *Cash Cows*, these products have big market share in a slow growing market, they generate substantial cash surpluses, even more of what they require to reinvest or to keep their market position. They are very valuable for companies, as they produce the actual profitability of the company and provide funds for investing in new ventures and supporting the growth of star products.

4.4 Strategic Analysis

4.4.1 Cluster Diamond analysis

Context of industry strategy and rivalry

In Mexico, around three quarters of the production of natural gas comes from associated gas, and this means that gas output, like oil, has been on a declining trend in recent years. The US Department of Energy and the Energy Information Administrations have assessed in 2018 that the Mexico's resources are sufficient to support significantly higher output of both conventional and unconventional gas; that the country shale gas potential is the sixth largest in the world, so the only piece missing is the investment needed to exploit this potential. With the energetic reform, Mexico has the chance to collaborate with foreign firms, mainly from the United States and ride on the shale gas production wave by creating synergies within the region and becoming the geographical area with the greatest production and export potential of natural gas. Currently both countries have 17 interregional gas pipelines and there are about 20 more under construction (EPA, 2017). In terms of rivalry, the region, mainly in the US has experimented in the past few year a breakthrough, new companies have emerged, new technologies and infrastructure have been developed and universities have adapted their lines of study to energy transition, more

competition creates better practices and develops better technology and knowledge. All this could be transferred to Mexico and boost the entire competitiveness of the region to successfully confront their biggest competitors in production and export of NG which are Russia and Australia.

Factor conditions

The greatest advantage of Mexico in the natural gas industry is its geographical position. Being a neighboring country of the largest producer and the largest consumer of natural gas. This advantage means that Mexico can receive all the expertise developed by the United States and quickly apply it in the country. Competition for the NG market in the US has led to important technological developments such as the technique of fracking to produce gas at lower cost, as well as the development of a robust pipeline infrastructure that leads to low distribution costs, also they have developed better economies of scale. Most of the universities in the southern United States and the Gulf area already have departments aimed at promoting the ET by using the current potential of natural gas as a transition element. Mexico being part of the United States, Mexico and Canada Free Trade Agreement (USMCFTA) has the possibility of exchanging knowledge, train the work force, have access to better costs of infrastructure inputs and mainly have access to very attractive costs of the raw material which is the NG itself.

Demand conditions

As CNH (2018) indicates the demand for energy in Mexico has increased by about 25% since 2000, however, the per capita consumption of energy still among the lowest within the countries that conforms the OECD (IEA, 2018b). Energy from fossil sources still represents 90% of the consumption. In the last ten years demand has begun to change towards a greater use of NG, especially in the production

of electricity. Projections through year 2040 elaborated by the EIA indicate that NG will account for almost 70% of the primary energy demand globally. In the past decade the demand increased in both Mexico and the United States by 70%, derived to the boom in shale gas production in the United States and the willingness of the both governments to develop international gas pipelines. The main source of demand is for electricity production, but the industrial residential consumption are growing at double digits each year. The demand of natural gas in the chemical industry has also double its consumption being a more price competitive than products derived from the oil.

Some risks are present too, Mexico energy transition occurs at different pace across the country, most of the rural areas still using wood for heat and cooking, and most of the low socio economical sectors in urban areas still using liquified petroleum gas (LPG) exchangeable containers.

Related and supporting industries

In the development of the NG industry other industries are also growth hand to hand with it. The academy, mainly in the southern United States and northern Mexico, including the Mexican Petroleum Institute (IMP - Instituto Mexicano del Petroleo), have developed new technologies to achieve greater efficiency in the extraction and production of hydrocarbons. The financial industry has contributed with the capital to finance the development of infrastructure and the exploration of new wells. The service industry provides the consulting, maintenance and necessary outsourcing activities, including industrial safety and civil protection requirements. The health industry provides occupational medicine, hospitals, and the transportation industry through boats, trains and pipes that are needed for the transportation of NG, finally the government itself is benefited by collecting higher taxes and driving the generation of new jobs.

There are some disadvantages too, if the production of NG explodes as expected in the region and the demand grows as well, the need to develop storage infrastructure across the country will rise, the cost and time of developing could affect the time of implementation of the cluster.

Government

As mentioned in the contextual framework, the energy reform of 2013 has laid the foundations for the energy transition in Mexico and the acceleration of the country's energy development. During the first years of the implementation of the mentioned reform, global energy companies have arrived in Mexico and have shown their interest in generating direct investment in the productive chain of hydrocarbons and renewable energies. The same reform has strengthened autonomous bodies such as the CNH and the CRE to make transparent decisions and regulate competition. The new free trade agreement of North America, USMCFTA, includes a chapter on energy and one on technology transfer, which will make it possible to form a solid commercial block and that in turn will promote a faster energy transition in Mexico taking as an example the US where they have used the NG as the intermediate element.

However, the risk of geopolitical factors are present, the ownership of the lands where the pipelines will cross in Mexican territory, together with the current level of criminal activity in the region present a disadvantage that only public policies can solve.

The end of Pemex's monopoly will open the door for competitiveness in Mexico, a number of changes made by the energetic reform are encouraging the private sector participation in the energy market and in the NG industry, developing infrastructure and investing in research and developing. New marketing companies are already looking for a complete open market by 2020 in which prices will be fully determined

by the market (Gobierno-De-Mexico, 2013; Royal-Dutch-Shell, 2018b).

The fundamental element for the NG industry in Mexico and with it the ET to reach the success depends on the government to facilitate its implementation and giving time to mature, getting a proper communication and interaction among the government organisms involved in the energy industry, i.e. the Ministry of Finance and Public Credit; the Ministry of Energy; the Ministry of Environment and the autonomous regulatory agencies like the CNH and CRE (Rojey, 2009; IEA, 2018a).

Chance

Mexico faces a big chance for ride up quickly and efficiently to the international wave of the energy transition. Again, thanks to its geographic location Mexico faces the opportunity to build a bright energy future. United States will consolidate as the largest producer of NG taking advantage of its low production costs and its rampant NG industry. The chance will be even bigger within the next five years where the consumption of the two most populous countries in the world, China and India, will increase substantially, considering that every year a greater part of its population migrates to cities reaching better living standards, which leads to a higher level of energy consumption, both countries have signed the Paris Agreement so most of the growing energy consumption will come from alternative sources such as NG and renewables (IEA, 2018a). However Mexico and the US will need to develop a strong and efficient transport industry for shipping NG production overseas, as stated above, China and India will become strong consumers of it and the northamerican product will compete with imports from middle east and Russia.

In figure 4.4 shows how the Porter's diamond will look for the NG cluster in Mexico northeast – US Southeast and US Gulf coast region.

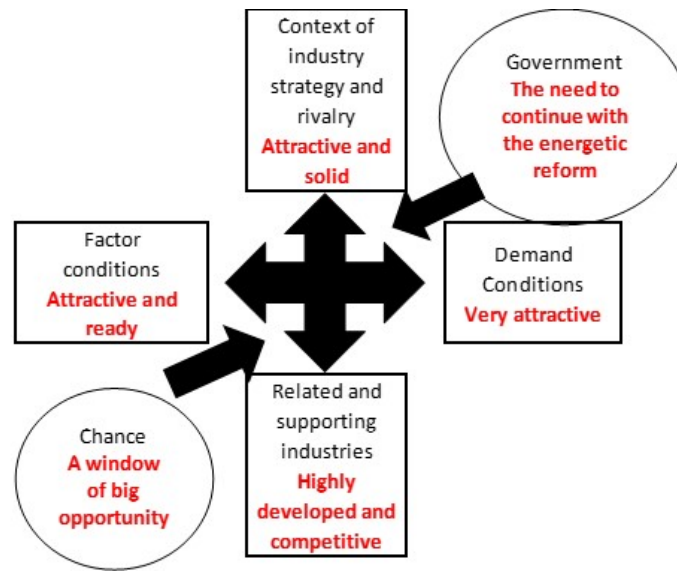


Figure 4.4: Diamond Analysis (Own elaboration).

4.4.2 Five Forces that shape strategy

Power of buyers

In Mexico currently the power of buyers is relatively low. The main importer of NG and the owner of most of the infrastructure is Pemex. The aim of the energy reform is to make Mexico an appealing market for international companies to invest and develop infrastructure and marketing channels so consumers will have different alternatives to Pemex. There are six kinds of customers for natural gas: the electric sector, industry, oil exploration and production, residential, services and transport (CNH, 2018). Currently the major customer in Mexico for natural gas is the Federal Electricity Commission (CFE - Comision Federal de Electricidad) as they are moving from fuel oil to NG to produce electricity. According to IEA (2018a), in the next ten years the consumption for the electricity sector will growth 36% and will represent a 82% share of the kind of energy that the sector will consume, with the ER private companies are allowed to produce and distribute electricity so end user prices will

tend to decrease. A similar growth, 31% will experience in the industrial sector and the share of natural gas within the fuels consumed will be around 64%. Even the industry related to oil exploration and production consume NG, current penetration of NG in this sector is still very low with barely 12%, however a growth of 38% is expected in the following 10 years. It should be noted that the new residential developments for both popular sectors and middle / upper classes are considering since the initial blue prints planning the infrastructure for a NG network supply. In the services sector, a similar situation as the residential occurs, penetration still well low of the liquefied petroleum gas (LPG), but a substantial growth of 69% is expected in the next 10 years, with which its participation will be close to 20%. Finally, in the transport sector will remain the smallest one, gasolines and diesel will continue with a big share of the energy utilized, NG share is expected to be no more than 1% being surpassed by hybrids and electric energy.

Power of suppliers

Before the energy reform, the Mexican NG market was a monopoly in its exploration and production phases managed exclusively by Pemex. This is the reason why the power of the suppliers in Mexico is considered very strong, since there is only one first hand seller. The stated owned company has different priorities to NG production, such as oil extraction and production and fuel supply, reason for the neglect on exploration and production of NG. During the 2010-2017 period, NG production in Mexico declined by an average of 4.7% annually, reason why Mexico has become a net importer of NG. This product is mostly supplied by the United States, which, by using a wide network of gas pipelines and the fracking technique is able to provide NG at very competitive prices, much more than if it were produced domestically.

Beginning in 2016, some private companies have begun to produce and distribute NG in the country and based on calculations and studies by the CNH (2018), it is

affirmed that Mexico is in a strong position to produce NG in a competitive manner by having public-private partnerships, which are allowed in the ER, particularly with firms located in the region conformed in the southeast US.

Threat of new competitors

The NG industry in Mexico currently does not really have threats from new competitors. The threat would be more to the existing monopoly of Pemex when the market gets open to foreign firms. The competitiveness that would occur with the entry of large international energy companies to Mexico and the investment in infrastructure that would come with them, would result in greater penetration in the consumer market, with better prices for the consumer, both for the industry and society. The threat of new competitors can be defined as strong if the energetic reform continues.

Substitute products

NG competes with various substitute products. Oil, gasolines, diesel, LPG among others and also with products from coal as the fuel used in mines and cement factories. In addition to petroleum and coal derivatives, NG also has renewable energy as a potential substitute product, which, even though their use is incipient in the Mexican market, have the potential to replace it in the future. Based on the foregoing, we can affirm that the threat of substitute products is strong.

Current competitors

Mexico is currently a monopoly market, where almost the entire volume consumed is imported exclusively by Pemex. It is fair to say that there is only one player that has a strong power to manage the offer and the price of the product to handle the demand in the country but that will completely change when the ER mature, and

with the current weak financial situation of Pemex makes the market very attractive for large international companies to enter and compete fiercely.

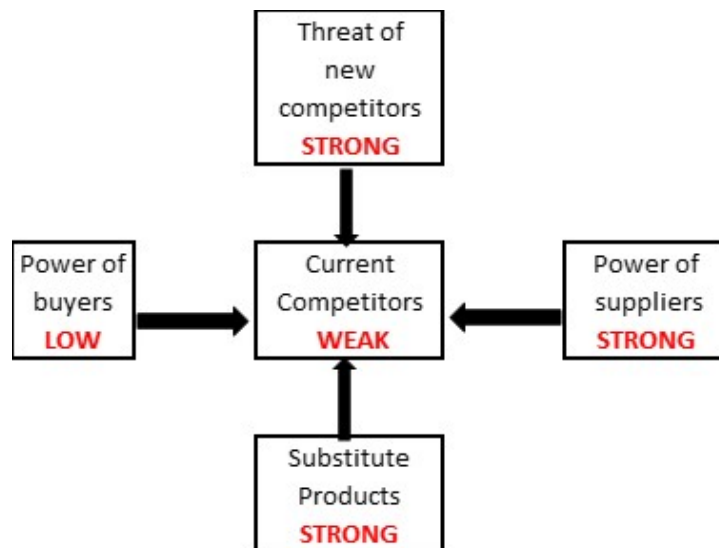


Figure 4.5: Five forces that shapes competitiveness in the Natural Gas Industry in Mexico. (Own elaboration).

As a result of the previous analysis, figure 4.5 gives the reader a perspective of how the five forces will interact in the gas natural industry in Mexico.

4.4.3 Boston Consulting Group matrix

Question marks

Renewable energies are considered as a question mark by the methodology used since they are still in the development phase but have good prospects of becoming a star. The use of them as a primary form of energy is the ultimate goal of the energy transition, however it is necessary to continue with the current phase of technological development to increase their penetration in global consumption, by making them more accessible to society and industry (which are its main consumers) both economically and physically.

Mexico presents a great potential for the adoption of these energies. Thanks to its geographical position, it receives large amounts of solar rays every year and in the southeast of the country there are large valleys that produce strong winds to impulse wind farm generators. The energy reform and the energy transition law have specific sections for the promotion of this type of energy, which is why Mexican society and industry are in a position to rapidly adopt this type of energy, regardless of its technological progress.

Stars

A natural raising star in the world is the Natural Gas, as Birol et al. (2010) indicates. The golden age of NG is approaching (Hix et al., 2012), according to EIA (2016) the annual consumption growth rate is doubling oil and coal, developed countries are already switching energy generated by oil and coal to energy generated by NG while renewables continue to develop, this is the reason of the NG growth rate. In Mexico, with the energy reform of 2013, mechanisms and agencies were created to encourage greater use of NG, an example of this is the five-year plan to expand the integrated national NG transport and storage system (SENER, 2015), which means that Mexico is joining the global trend of accelerating the energy transition by using NG as the intermediate element.

Dogs

Nuclear energy, a clean energy, in 2018 only represented 5% of total energy consumption in the world (CNH, 2018). Its growth rate was seriously affected by the Fukushima accident in 2011 and the previous incident in Chernobyl in 1986. Before the Fukushima incident France and Japan were strongly pushing for this kind of energy to become the intermediate step for the energy transition. France and India still performing test to make nuclear technology safer and be considered as the main

alternative energy that will replace fossil fuels, together with renewables. Mexico has just one nuclear facility in Laguna Verde in Veracruz state, however no relevant investment has been made over the past decade.

Cash cows

Energy from oil and coal still accounts for more than half of global consumption, and will continue to be an important part of world energy consumption for a long period. New wells have been discovered in deep waters so the production will be more expensive, and the international efforts to fight climate change will demotivate the use of them as a main source of energy. Its growth rate compared to the world population growth is lower so a smaller participation in the global consumption is expected, in the medium term most of its consumption will be occupied by NG and in the long term by renewable energies. However until 2050 will remain as the main source of energy consumption and it will bring the necessary funds to develop alternative energies.

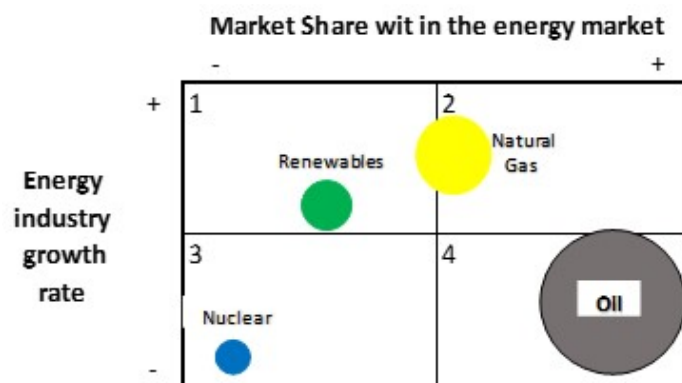


Figure 4.6: Boston Consulting Group Matrix Analysis (own elaboration with data taken from IEA world energy outlook, 2018 and INEGI, 2018).

4.5 Conclusions

In order to get control over the climate change the ET must be implemented in every country, being Mexico not the exception, however this transition can't happen as fast as desired in all nations and different steps should be taken individually to assure that the transition comes to an end in a successful manner. Mexico has joined this effort through the "Energy Reform" issued in 2013 that has settled the bases for a solid ET by opening the energy market to new competitors, suppliers and technologies.

Through strategic tools, *Porter's cluster diamond and five forces together with the Boston Consulting Group matrix*, we conclude that Mexico faces THE big opportunity to accelerate its energy transition while growing its natural gas industry. As analyzed in the cluster diamond, the government should take the role of a facilitator to attract the required foreign and domestic direct investment and through this impulse the developing of the infrastructure required to boost the commercialization of NG across the country. Porter's diamond have shown that Mexico has the chance to receive developed ET knowledge coming from the United States, and with it the cluster could become the undisputed global leader of the NG industry, generating the necessary funds to accelerate the development of renewable energy and make it more accessible to the majority of the population. The five forces analysis have shown that today, with no ER fully implemented, Mexico presents an unattractive scenario for private investment in the energy sector, however with the bases and the proper implementation of the ER Mexico could be considered as a very attractive market, both for energy consumption and production of alternative energies in the upcoming future.

Finally, based on the analysis of the Boston Consulting Matrix, we observe that within the Mexican energy portfolio the NG is a rising star, its use in the industry and society is growing at a faster phase than other energies, even renewables.

Mexico, through Pemex should focus on the exploration and production of oil, that is a cash cow, an activity where the highest profit margins are obtained and very attractive for global energy companies to invest in and together with the ER the state company is able to obtain funding and state of the art technology. The renewable energy industry, even though it is being strongly promoted internationally, its level of development is not yet enough to compensate the energy requirement in the world including Mexico, so its development should continue but can't be the short term solution for the ET.

Then, in order to achieve a successful energy transition, the Mexican NG industry is the transition element required, so it should be properly developed taking advantage of all the possible forces and synergies mentioned above.

Chapter 5

Conclusions and Future Research

In the study of the contextual framework we could conclude that climate change is a reality that affects humanity and the way it lives. As stated in this research, the increase in the world population, as well as the increase in the migration from rural areas to urban areas, have caused greenhouse gas emissions to increase exponentially in the last five decades. However, this migration has brought also beneficial effects for a large part of humanity: social welfare has improved by having greater access to services like transport, standardized climate, drinking water, electricity, etc. This is the reason why the leaders of the nations have joined forces to pursue a common goal, which is to continue improving the quality of life of people without affecting the environment for future generations, this is known as Sustainable Development. We also have commented that in several forums sponsored by the United Nations Organization such as the Tokyo Protocol and the Paris Agreement, the vast majority of countries have agreed to reduce the emission of polluting gases with the goal of keeping below two celsius degrees the increase of global temperature increase within a planned horizon to 2050. In order to achieve the previous goal the process known as the “Energy Transition” has started globally, which translates into boosting the production and consumption of renewable instead of the current

flow of energy coming most from fossil sources, mainly oil and coal. This transition is progressing at different speeds in each country or region, with Western Europe being the most advanced and in which the strategies that have been followed to achieve the goal set for 2050 are better documented. However, any transition requires a phased and strategically planned moves finding the key elements that will facilitate a smooth transition. Having investigated best practices globally and by performing quantitative and qualitative analysis and by evaluating the current state of the energy transition in Mexico and its perspective for the upcoming years we have reached a conclusion that in order to achieve a successful transition, the Mexican **Government** has to play the role of the **Driver Intermediary** that impulses the transition in our country working along with the other three members of the quadruple helix: Industry, Academy and Society, but also, as the ultimate goal of any government is to increase the welfare of its population, the energy transition in Mexico can't be reach in the short term, so a strategic plan has to be crafted in order to move smoothly and efficiently from fossil energies to renewable energy. In the case of Mexico we have concluded that the **Transition Element** is the **Natural Gas**, element that will play the role of the link that will build the bridge between fossil and renewable energies, as demonstrated in chapter four where we have found that Mexico is in a privileged geographical position to take advantage of the it and the global boost that this kind of energy is experimenting.

5.1 Best Practices in Climate Change Control

In Chapter 2, a comparative analysis was carried out on the various climate change control initiatives with the objective of identifying and learning the best practices developed by different countries in Europe and that could be replicated in other countries.

Germany and the Netherlands were identified as the countries with the climate control strategies that could be replicated more efficiently by the vast majority of nations. In both countries, the quadruple helix model of knowledge transfer (Government - Industry - Academy - Society) has been successfully implemented. From these best practices, we learnt the key actions that can be standardized and transferred in order to implement a successful energy transition globally. First is to build a successful and continuous cooperation between the four members of the quadruple helix, establishing quantifiable SMART goals (*Simple, Measurable, Achievable, Related to the main objective and within a Time frame*), remarking that one of the members should take the lead and coordinate the effort of the other three members of the Technology Transfer model, we have called it the **Driver Intermediary**. The second best practice identified in Europe is that, as the production of renewable is not enough yet to cover for the full consumption of the energy required, a **Transition Element** has to be utilized, in the research we identified that both countries have used the Natural Gas as this element, some other countries like France are using the Nuclear energy and the Nordic countries the Bio fuels, however these two last models couldn't be replicated as well as the Germany and Netherlands ones.

5.2 Government- The Driver Intermediary

In chapter three, once the best practices of the most advanced countries in the energy transition were identified, a quantitative analysis was carried out to determine if in Mexico the government could be the appropriate agent to impulse the energy transition. Through an analysis of game theory we have concluded that in fact, the government should be the Driver Intermediary which will impulse the transition. Our exercise was based by finding Nash Equilibrium in a game with three agents (government, industry and society) and three stages, being the first in which there

is no government intervention; a second stage where the government carries out the action of imposing taxes on the production and consumption of energy from fossil sources and subsidies for the production and consumption of renewable energies in order to encourage the adoption of the latter and a final stage in where the industry observes taxes and subsidies, it decides its production plan in favor of renewable energy and then the consumer (society) looking for its own welfare adopts them as they are now more accessible.

5.3 Natural Gas -The Transition Element

In the contextual frame of chapter four, we analyzed the energy reform together with the energy transition law issued in 2013 evaluating the advantages and disadvantages of both, concluding that even when the government performed multi approach forums including Academy, Industry and Society points of view, during the development of secondary laws and regulations they were carried out alone by the government, which generated a distortion in the spirit of the reform. Is worth to affirm that the biggest risk for the energy transition could come from two decisions that the government could take. The first one is to abandon the energy reform, creating a lack of trust within the global community that had already invested in Mexico and the second to think that going back to fossil fuels is the base for the energy success in the country, while almost all countries in the world are moving towards an Energy Transition to renewable.

In this chapter, a qualitative investigation was carried out, through deductively strategic planning tools, that is, from the general to the particular to assess whether Natural Gas could be the appropriate transition element for Mexico. Through the Porter diamond tool, we analyze the situation of the natural gas industry in Mexico,

reaching as conclusion that Mexico is in an exceptional geographical location for the use of this energy. The region conformed by the Mexican northeast, the southeast of the US and the Gulf of Mexico is one of the two geographical areas with the greatest potential for natural gas production. The already flourishing natural gas industry of the US in terms of infrastructure, reservoir exploitation technology, academic curriculum and skilled labor allows the transfer of technology and knowledge to Mexico and naturally it will create strong synergies which could catapulted the region to the global greatest potential for production and consumption of natural gas. The second analysis was carried out through the five forces of Porter in which we evaluate the attractiveness of the industry, in this exercise we conclude that even when Mexico is still handled by a stated monopoly, the Energy Reform, is making the industry globally attractive for its development. There are few players in the market, the market size its also very attractive for large global energy companies to invest in; it will attract many new competitors that will foster competitiveness and a strong technological development and investments; the substitute products, like the fossil sources will remain for some time, but its weight in the mix will be reducing as they in the phase of declining of its life cycle, while the renewable energies will be continuously developing but not considered as a strong substitute in the short term. The last analysis, was performed through the product portfolio matrix of the Boston Consulting Group, in which we analyzed the current Mexican energy portfolio with the conclusion that Mexico should focus its current major energy source -Oil production only in the exploration and production activity so it can be used as the Cash Cow that will provide the funds necessities for developing new energy alternatives. We conclude that the Natural Gas is a rising star, so the Mexican Mexican government must allocate part of the funds generated by oil exploration and production to boost the development of this industry. The Renewable energy still as a Question Mark, its current level of development requires a lot of investment

to improve the rate of adoption in the country; and finally, we conclude that the Nuclear energy is a dog and Mexico should abandon the development and focus in Oil exploration and production, a fast development of the Natural Gas Industry and continue developing the Renewable option by adopting globally technology.

5.4 The Energy Transition Strategic model for Mexico

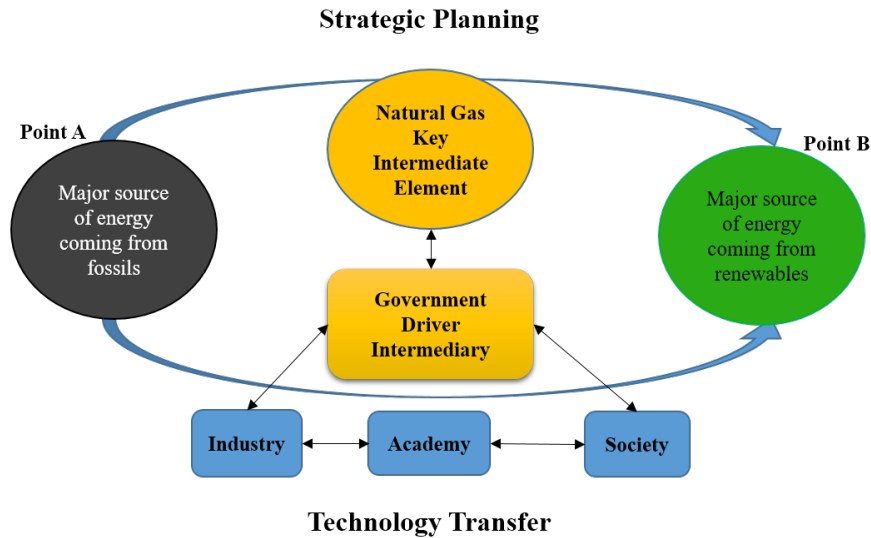


Figure 5.1: The Energy Transition Strategic Model in Mexico

The energy transition process in Mexico must be planned according to two strategies:

1. To use the quadruple helix model of technology transfer in an efficient manner, in which the federal government acts as the driving agent that drives the energy transition process, by using the following tools:

- Pignuvian taxes for the production and consumption of fossil that will decrease the demand of these kind of energies.
 - The resources coming from these taxes should be labeled as subsidies for the development of renewable energy sources in three ways:
 - Giving part of them to the industry, so that the rate of return on investment in renewable technology is attractive enough to invest in them.
 - Another part of them should be directed to academic research to develop more rapidly new technologies that allow the adoption of these sources to a greater extent.
 - Another part must be transferred directly to the final consumer, that is, to the society, so that renewable energies are more accessible encouraging their rapid adoption.
2. The second strategy is to develop the natural gas industry as the key intermediary element that will allow to move from the current situation of massive use of fossil fuels, to the desired situation of a major energy mix coming from renewable through:
- Letting the energy reform to mature, in where private investment and technology transfer is allowed in the generation of this energy.
 - Improve secondary laws derived from this reform with the participation of the other members of the quadruple technology helix, that is to say of the industry, which is the producer and marketer of this energy; of the society that is the consumer of it and of the academy that is the one that drives the research and development of new technologies that encourage the rapid adoption of them. .
 - Take advantage of the privileged geographical location of our country encouraging the transfer of technology developed in the United States, in

aspects such as infrastructure, security, academic curriculum and, most importantly, access to financing at a lower cost.

The Energy Transition in Mexico at a glance

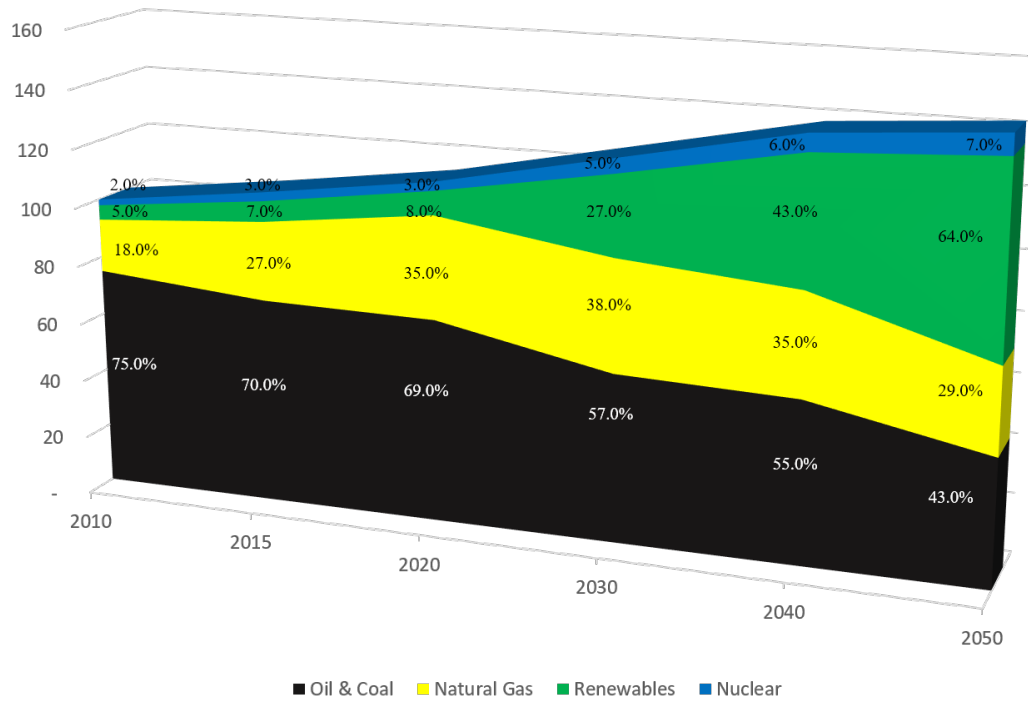


Figure 5.2: The Mexican Energy Transition 2010-2050

5.5 Future Research

The present thesis has the purpose of being a living thesis. Its structure allows each of the chapters to be extracted and reproduced as an individual article that also could be updated or revised every year according to the progress in the evolution of technology, government actions, future environmental regulations, global agreements and global economy.

The immediate work after this thesis is to evaluate the impact of the new public

policies of the Mexican federal government of the 2018-2024 period and the continuity or not of the energy reform.

A second article derived from this thesis will be to evaluate the operation of the quadruple helix energy sector in Mexico.

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