COMILLAS
UNIVERSIDAD PONTIFICIA
ICAI

MASTER IN THE ELECTRIC POWER INDUSTRY

MASTER'S THESIS

INTEGRATED MODELING OF ELECTRICITY AND HYDROGEN MARKETS: ANALYSIS OF MODELING DIFFERENT CONCEPTIONS OF GREEN HYDROGEN

Author

Álvaro Ferrero Baz

Supervisors

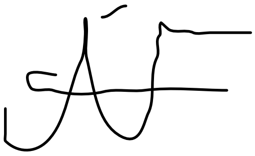
Fco. Alberto Campos Fernández

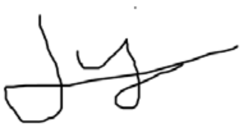
Luis Alberto Herrero Rozas

José Villar Collado

Madrid

September 2023

Information of the Student	
Name: Álvaro Ferrero Baz	
Email address: 201702917@alu.comillas.edu	Phone Number: 608 97 79 29
 Date & Signature:	

Information of the Supervisors	
Name: Alberto Campos Fernández	
Affiliation: Institute for Research in Technology	
Email address: acampos@comillas.edu	Phone Number: 655 58 28 64
CAMPOS FERNANDEZ FRANCISCO ALBERTO - 11836144E Firmado digitalmente por CAMPOS FERNANDEZ FRANCISCO ALBERTO - 11836144E Fecha: 2023.09.21 16:56:40 +02'00' Date & Signature:	
Name: Luis Alberto Herrero Rozas	
Affiliation: Institute for Research in Technology	
Email address: lherrero@comillas.edu	Phone Number: 670 97 55 31
 Date & Signature: 21/09/2023	
Name: José Villar Collado	
Affiliation: Institute for Systems and Computer Engineering, Technology and Science	
Email address: jose.villar@inestec.pt	Phone number: 639 16 30 59
VILLAR COLLADO JOSE - 00818527A Digitally signed by VILLAR COLLADO JOSE - 00818527A Date: 2023.09.21 16:28:57 +01'00' Date & Signature:	

Contents

INTRODUCTION AND MOTIVATION

The electricity sector and industry are currently undergoing a process of decarbonization and energy transition. In this challenging scenario, green hydrogen stands out as one of the most promising alternatives to achieve these objectives. Although promising, the use of green hydrogen presents some remarkable challenges, one of the most severe being the integration of hydrogen markets into electrical markets.

The aim of this thesis is to delve into advancing the study and modeling of green hydrogen production as part of a Nash equilibrium model for the electricity and hydrogen market. Among other considerations, the influence of various scenarios will be analyzed through different case studies. These scenarios include considering that green hydrogen production is exclusively based on renewable spillages, renewable production that is not spilled-off, or when the electricity price is zero.

Prior to this study, an analysis of potential resolution techniques will be conducted for situations in which the electricity price is a primal variable of the market model. Among these techniques, the use of a mixed complementary problem for resolution is not ruled out.

This study holds particular relevance in the current context given the expressed intention of European countries to strengthen existing electricity markets. For years, and especially after signing the Paris Agreement in 2016, the European Union has made achieving climate neutrality by 2050 a top priority[1] . Spain and Portugal, as member countries of the European Union and signatories of the Paris Agreement, have developed strategies and objectives, resulting in various action plans and legislation to fulfill their part of the agreement.

Some of these texts will be further discussed in the references section of this annex, as they encapsulate the main motivation for undertaking this work—the expressed need by Spain and Portugal to advance in the study of the aforementioned challenging task of integrating hydrogen markets into current electricity markets.

[1] According to the UNFCCC, the concept of climate neutrality refers to "the idea that net greenhouse gas emissions are balanced and equal to, or less than, the emissions removed from the atmosphere through the planet's natural absorption."

OBJECTIVES

- Delve into the study of action plans and strategies developed by Spain and Portugal to achieve climate neutrality, particularly those concerning green hydrogen.

- Analyze the main characteristics and attributes that make green hydrogen an ideal solution for energy transition.

- Understand the legislation and requirements necessary for considering energy production through what is referred to as green hydrogen.

- Comprehend the dynamics of current electricity markets and the complexity of integrating hydrogen production.

- Advance in the modeling of green hydrogen production as part of a Nash equilibrium model for electricity and hydrogen markets.

- Evaluate the implications of modeling different approaches of green hydrogen production. Specifically, highlight the understanding of green hydrogen production based exclusively on renewable spillages, on renewable production that is not spilled-off, or in situations where the electricity price is zero.

PRELIMINARY TABLE OF CONTENTS

- **Introduction.** This first part will compile and elaborate upon the information presented in this annex. Addressing the theme, motivation, main objectives, methodology, and key concepts of the thesis. In this way, the first chapter of the master's thesis could be divided into:

  - **Key Concepts**
  - **Motivation**
  - **Objectives**
  - **Methodology**
  - **Conclusion & Results**

- **State of the Art.** The focus of this chapter will be to gather the most relevant information about this energy source, which is expected to be crucial in the transition towards a more sustainable future. This chapter may include the following sections:

  - **Objectives and Strategies for Hydrogen implementation.** This section will verse about the available documentation that holds the action plans of European Union, Spain and Portugal in the energy sector, particularly focusing on strategies or guidelines related to hydrogen, specifically green hydrogen.
  - **Green Hydrogen.** This section will gather the most significant information regarding the key characteristics of green hydrogen production, along with an analysis of the existing regulations.
  - **Electricity Markets.** This part of the chapter will address the overall dynamics of current electricity markets, focusing on the significant challenge of effectively integrating hydrogen production into the existing landscape.

- **Modeling Basis.** This chapter will compile the modeling basis necessary for developing a GAMS code, allowing for the evaluation of the various scenarios that will be discussed in this master's thesis. Within this chapter, the following areas will be further addressed:

  - **Modeling Constraints.** This section will enumerate and define the primary constraints to consider when modeling electricity and hydrogen markets.
  - **Resolution Techniques.** The potential resolution techniques for situations in which the electricity price is a primal variable of the market will be addressed within this part of the study.
  - **Nash Equilibrium.** To conclude this chapter, the concept of Nash Equilibrium will be analyzed, along with its modeling implications.

- **GAMS Code.** The development and explanation of the GAMS model code will have its own chapter, which will be divided into two sections.
    - **Base Model.** This thesis aims to advance an existing Nash equilibrium model for the electricity and hydrogen markets. In this initial section, the existing model will be presented and analyzed, as it will serve as a vital base for this project.
    - **Proposed Model.** This segment will include the progress and code modifications proposed for the different case studies to be analyzed in this master's thesis.

- **Scenario Analysis.** After completing the code, an analysis of the various proposed case studies will be conducted, aiming to conclude the efficiency and viability of each. These case studies will include assumptions such as green hydrogen production being exclusively from renewable overflow, from non-overflowed renewable production, or during periods of zero electricity price.

- **Alignment with the SDGs.** This master's thesis report will include a section dedicated to analyzing how this study aligns with the Sustainable Development Goals (SDGs).

- **Conclusions & Results.** To consolidate the information derived from this study, the thesis will include a compilation of the results obtained from the proposed model, along with a comprehensive analysis of the implications of these findings.

- **Potential Developments.** This thesis report will conclude with a list of topics of interest that may emerge from this study, deserving deeper investigation in future projects.

METHODOLOGY

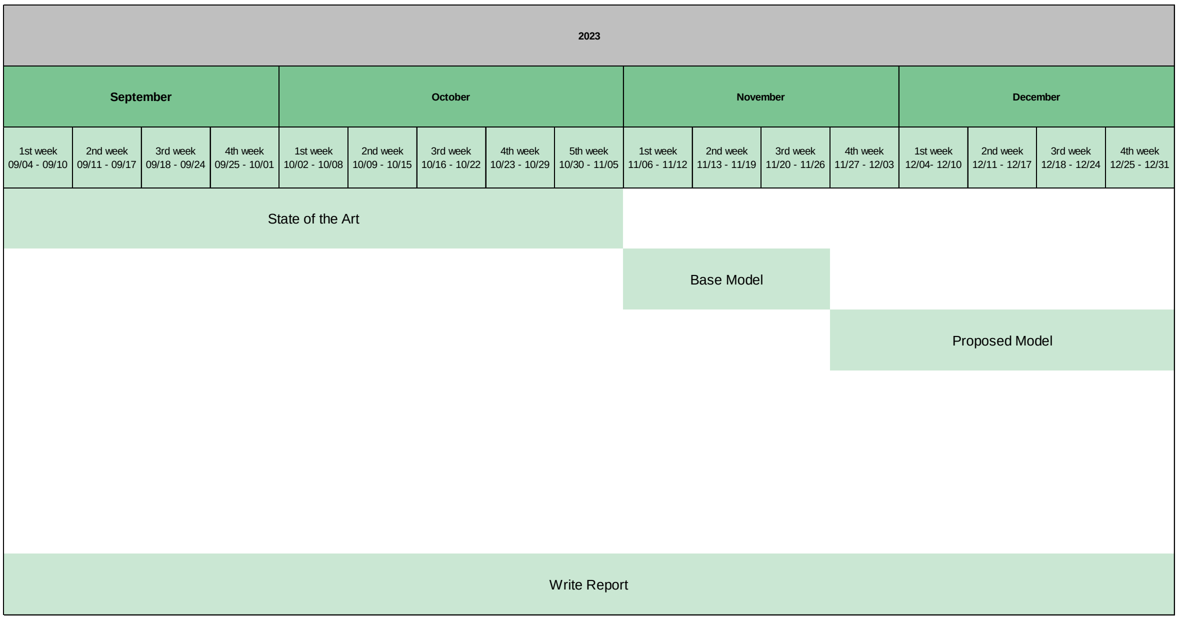
The stated problem will be addressed through the development of a GAMS[2] model utilizing optimization techniques to find the aforementioned Nash equilibrium. This model will include the fundamental variables, constraints, and objective function that represent the dynamics and relations between the electricity and hydrogen markets. The optimization techniques will be applied to achieve the Nash equilibrium, in other words, a state where no participant can benefit by unilaterally changing their strategy.

To address the problem, within the Resolution Techniques section, different solver types will be evaluated to determine the most suitable one for the proposed model. It is essential to find the adequate resolution technique, for solver types play an essential role in finding the optimal solutions to complex mathematical models.

[2] GAMS (General Algebraic Modeling System) is a high-level modeling system for mathematical programming problems. It allows for the formulation and solution of large-scale mathematical models, making it a suitable tool for this complex analysis.

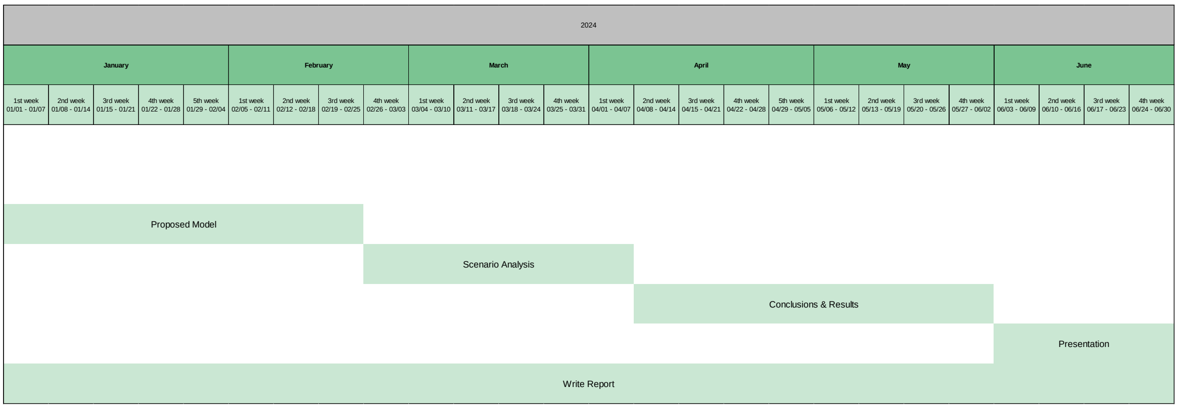
WORK PLAN

Figure 1. Work Plan 2023



Source: Original.

Figure 2. Work Plan 2024



Source: Original.

REFERENCES

The main references for this master's thesis can be grouped into three main categories. The first category will contain references related to the study of the state of the art, the second category will gather regulations and fundamental requirements concerning green hydrogen, and the third category will focus on modeling guides and essential references for writing the GAMS code.

The first group, related to the state of the art, should include the National Energy and Climate Plans of Spain and Portugal (PNIEC and PNEC). These documents contain the energy action plans for both countries. Other documents of interest for this study at a national level are the hydrogen strategies, which are focused on defining the guidelines and objectives regarding hydrogen. Finally, it is also helpful to analyze the objectives and guidelines agreed upon at the European level, as the decisions implemented by both Spain and Portugal are significantly influenced by the European decisions.

For the second category, the sets of rules for renewable hydrogen published by the European Commission will be particularly relevant. These rules outline the requirements set by the European Union to define what constitutes renewable hydrogen. Additionally, this group of references should include more technical articles that delve into concepts such as 'additionality' and help understand the principles of energy production through green hydrogen.

Finally, in order to model green hydrogen as part of a Nash equilibrium model for the electricity and hydrogen markets, available GAMS formulation guides and notes from various subjects at the Universidad Pontificia Comillas will be used as references. It's worth highlighting again that this project aims to advance an existing code model. Therefore, this existing base model will also serve as a reference for the proposed model.

In the following bibliography section, a list of references that will be crucial for the development of this master's thesis will be included. This list will be updated in the final thesis to incorporate all the files that ultimately served as references for the project.

BIBLIOGRAPHY

[1] Ministry for the Ecological Transition and the Demographic Challenge. (2023). *Spain - Draft Updated NECP 2021-2030.* https://commission.europa.eu/publications/spain-draft-updated-necp-2021-2030_en

[2] Ministry of the Environment and Climate Action. (2023). *Portugal - Draft Updated NECP 2021-2030.* https://commission.europa.eu/publications/portugal-draft-updated-necp-2021-2030_en

[3] Ministry for the Ecological Transition and the Demographic Challenge. (2020). *Hydrogen Roadmap – A commitment to Renewable Hydrogen.* https://research.csiro.au/hyresource/policy/international/spain/

[4] Ministry of the Environment and Climate Action. (2020). *Portugal National Hydrogen Strategy (EN-H_2)* https://research.csiro.au/hyresource/policy/international/portugal/

[5] United Nations Framework Convention on Climate Change (UNFCCC). (2021). *A Beginner's Guide to Climate Neutrality.*

[6] European Commission. (2021). *European Climate Law.*

[7] European Commission. (2020). *RePowerEU.*

[8] European Commission. (2020). *Fit for 55.*

[9] European Commission. (2023). *Commission sets out rules for renewable hydrogen.*

[10] Pototschnig, A. (2021). Renewable hydrogen and the "additionality" requirement: why making it more complex than is needed? *Florence School of Regulation.* https://fsr.eui.eu/publications/?handle=1814/72459

[11] GAMS. (n.d.). GAMS User's Guide. Retrieved from: https://www.gams.com/latest/docs/UG_MAIN.html