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MASTER´S IN THE ELECTRIC POWER INDUSTRY

FINAL MASTER THESIS

Assessing greenhouse gas emissions and other pollutants in achieving a net-zero Spanish energy system

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Tutor's signature

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1. *INTRODUCTION AND MOTIVATION*

1.1 Background

The European Union (EU) has emerged as a global leader in the development of climate-energy policy, recognizing the imperative to address the challenges of greenhouse gas (GHG) emissions and other pollutant, while promoting sustainable energy practices. Accounting for 10% of total global emissions on a production basis, the EU plays a pivotal role in the international efforts to combat climate change. The commitment to climate action is underscored by substantial energy policies in place for over two decades, featuring qualitative and quantitative targets encompassing pollutants reduction, increased renewable energy integration, and enhanced energy efficiency.

It is important to also address other pollutants such as SOx, NOx, and PM2.5, which have significant impacts on air quality and public health. SOx (Sulphur oxides) are mainly produced from fossil fuel combustion and contribute to respiratory problems and acid rain. NOx (nitrogen oxides) are emitted from vehicles and power plants, leading to smog formation and respiratory issues. PM2.5 (particulate matter less than 2.5 micrometers) can penetrate deep into the lungs and bloodstream, causing cardiovascular and respiratory diseases. Taking into account this pollutants and the GHG, in particular CO2 emissions, will be crucial for the future development of the energy sector.

The energy sector, including production consumption, transportation, and industry among others, is essential for achieving a sustainable future. This sector is about to undergo significant changes as efforts to meet climate goals increase. It's important to understand the current emissions from different energy sources and how these emissions will impact the future as we work towards decarbonization. This study focuses on the present-day emissions from various energy technologies, such as fossil fuels, renewables, and nuclear power. It examines how these emissions affect Spain's progress towards reducing greenhouse gases (GHG) and other pollutants like SOx, NOx, and PM2.5. These pollutants are important because they not only contribute to climate change but also impact air quality and public health. By measuring all types of emissions, we can create better strategies for energy planning. This will help ensure that Spain can meet its climate targets and transition to a cleaner, more sustainable energy system. Understanding the current situation and planning for the future is key to successfully reaching our decarbonization goals.

1.2 Spain Context

In Spain, as in the broader European context, energy systems face sustainability challenges related to resource use, management, and external costs. While analyzing these challenges, there is a growing recognition that efficient utilization of existing infrastructures is a priority to address increasing power demands and environmental concerns.

The energy generation landscape in Spain combines a diverse mix of sources, including fossil fuels, renewable energy, and nuclear power. While the focus often centers on the variable nature of renewable energies, it is crucial to consider the entire process of power generation and consumption for a comprehensive understanding of emissions, including CO2, SOx, NOx, and PM2.5.

The challenges associated with adjusting the output of fossil fuel plants, especially natural gas and coal-fired plants, have significant effects on emissions and efficiency across the entire energy sector. Sudden increases or decreases in power generation, known as cycling, happen for various reasons. Among the reasons is making way for renewable energy, maintenance, equipment failure, or sudden changes in demand. Integrating variable renewable resources like wind and solar with existing power plants requires these fossil fuel plants to frequently adjust their output. Energy storage technologies can also help balance these fluctuations.

Cycling impacts the efficiency and emissions of power plants, especially coal-fired plants designed to operate steadily. Frequent adjustments can lead to reduced power generation efficiency and increased fuel consumption, which in turn leads to higher emission rates per unit of electricity generated. Therefore, it's important to understand how variable energy sources are integrated with existing power systems and the resulting emissions challenges.

This project aims to contribute to the ongoing discussion by exploring the performance of the Spanish energy system in response to ongoing changes in the sector to meet decarbonization and climate objectives. The study examines emissions from various energy technologies, including their final uses in transportation, industry, and residential sectors, operating under different conditions and their relationship with different energy sources. By analyzing various scenarios, the study assesses potential emissions reductions across the entire energy landscape. The goal is to provide evidence-based strategies and alternatives to improve the reliability and sustainability of future energy systems in Spain, considering emissions from production to end-use processes.

1.3 Motivation

The motivation for this study comes from the urgent need to comprehend and address the difficult challenges associated with achieving a net-zero Spanish energy system, with a focus on assessing greenhouse gas emissions and pollutants. The following key factors underscore the significance of this project.

1.3.1 Global Imperative for Sustainable Energy Transition

In a world dealing with the consequences of climate change, the necessity to transition to sustainable energy systems has created an urgency. The energy sector, as a major contributor to global emissions, stands at the forefront of this challenge. Understanding the dynamics of emissions is essential to redirect the transition towards cleaner energy sources and mitigate the energy industry's environmental impact.

1.3.2 Spain's Commitment to Net-Zero Emissions

Spain, like many nations, is actively committed to mitigating climate change by striving for a net-zero emissions future. This commitment aligns with international agreements such as the Paris Agreement, where nations pledge to limit global warming to well below 2 degrees Celsius. Assessing and understanding the current state of greenhouse gas emissions and other pollutants in the Spanish energy system is crucial for creating effective policies and strategies to achieve these targets.

1.3.3 Role of the Electric Power Industry in Spain

The energy sector plays a central role in Spain's economy, being fundamental to the energy needs of industries, businesses, and households. As the country aims to diversify its energy mix and reduce reliance on fossil fuels, it becomes extremely importatn to assess the emissions landscape comprehensively. This study seeks to provide information that can clear the direction of policy decisions, technological investments, and regulatory frameworks within the sector.

1.3.4 Utilizing the openMASTER Model for Future and Concrete Analysis

Using the openMASTER model in this research adds a unique dimension to the study. This model is dynamic and modular, making it possible to completely analyze the Spanish energy system. It incorporates various important factors, such as primary energy sources (like fossil fuels and renewables), conversion technologies (Energy transformers of primary commodities), energy storage solutions, supply technologies, and energy services. By including all these variables, the openMASTER model provides a comprehensive framework for understanding how different parts of the energy landscape are interconnected and impact each other.

1.3.5 Bridging Knowledge Gaps and Guiding Policy Decisions

Despite progress in renewable energy integration, knowledge gaps still difficult the understanding of the complete spectrum of variables critical emissions in the energy sector. This study aspires to clear up these gaps by employing a robust analytical framework. The findings are anticipated to provide valuable directions for policymakers, energy planners, and researchers, guiding evidence-based decisions to clear Spains path to go through towards a sustainable, net-zero energy future.

2. *OBJECTIVES OF THE MASTER THESIS*

The overarching goal of this master thesis is to assess greenhouse gas emissions and other pollutants in the context of achieving a net-zero Spanish energy system. The research aims to provide a comprehensive understanding of the current emissions landscape, analyze the ongoing transition towards a sustainable energy system, and leverage the openMASTER model for holistic assessment.

2.1 Specific Objectives

The specific objectives of the master thesis are as follows:

2.1.1 Evaluate the Current Emissions Landscape

The first objective is to meticulously evaluate the existing emissions landscape within the Spanish energy system. This involves a thorough analysis of current greenhouse gas emissions and other pollutants such as SOx, NOx, and PM2.5, considering the diverse sources and sectors contributing to the environmental footprint. By establishing an understanding of the sector, the study will be able to identify critical areas for emissions reduction and mitigation strategies.

2.1.2 Analyze the Transition Towards a Net-Zero Energy System

A crucial aspect of the thesis is to analyze the ongoing transition towards a net-zero energy system in Spain. This involves assessing the impact of policy interventions, technological developments, and changing energy consumption patterns on emissions reduction. By conducting a dynamic analysis, the research aims to capture the trajectory of the energy system evolution and study the effectiveness of current initiatives and propose an upgrade.

2.1.3 Utilize the openMASTER Model for Future and Concrete Analysis

Integrate the openMASTER model into the research framework to conduct a complete assessment of the Spanish energy system. The utilization of this model allows for the incorporation of various variables, including primary energy sources, conversion technologies, transformed energy with storage, supply technologies, and energy services. The objective is to use the model's dynamic and modular structure to gain insights into the interconnected components of the energy landscape.

2.1.5 Assess the Role of Energy Services in Emissions Reduction

Examine the role of energy services in the global context of emissions reduction. This includes evaluating the efficiency and sustainability of energy services in meeting consumer demands while minimizing environmental impact (Main objective of the ongoing policies). The objective is to identify opportunities for upgrading energy services to align with the goal of achieving a net-zero energy system.

2.1.6 Provide Policy and Strategic Recommendations

Assembling the findings of the study into actionable policy and strategic recommendations. The research aims to offer evidence-based insights to policymakers, energy planners, and stakeholders involved in shaping the future of the Spanish energy system. Recommendations will encompass measures for emissions reduction, technology integration, and policy adjustments to expedite progress towards a sustainable, net-zero energy future.

3. *MODEL EXPLANATION*

To address all of the different variables of the energy sector, this master thesis uses the openMASTER model, a dynamic and versatile tool designed for comprehensive energy system analysis. The model's configuration is a critical aspect, involving the precise definition of sets and parameters. Time horizon grouping, temporal resolution, and the representation of seasons, days, and hours are crucial considerations, striking a balance between granularity and computational load.

Complications in the model include the definition of primary energy vectors, conversion technologies, and relationships between interconnected sets to ensure consistent energy and matter flows. Despite its complexity, the openMASTER model has been crafted in a modular and user-friendly format, emphasizing accessibility for all users. Alongside the model code, input and output modules, as well as a viewer, contribute to ease of use and interpretation of results.

The modular architecture of openMASTER ensures flexibility, allowing users to navigate through the model's components seamlessly. Input and output data modules serve as vital connectors between the model and external data sources, facilitating efficient data transmission and result generation. This approach not only enhances interoperability but also makes the model adaptable to diverse energy scenarios.

It is crucial to acknowledge that while the openMASTER model demands a meticulous configuration process, it offers a modular and accessible framework. This aspect aligns with the broader goals of promoting transparency, ease of use, and adaptability in energy system modeling.

This comprehensive analysis aims to answer critical questions such as the impact of transitioning from solid fossil fuels to gas, the role of increased renewable penetration, and the influence of international electricity trade on carbon emissions. By understanding these dynamics, the study aims to contribute valuable insights to the ongoing discourse on effective climate-energy policies.

4. *METHODOLOGY*

The methodology for this master thesis is structured into three distinct phases, each corresponding to a month of the research timeline. These phases encompass data collection and parameterization, study case application, and results analysis and document elaboration.

4.1 Data Collection and Parameterization (1st Month)

4.1.1 Data Collection Process:

- Develop a comprehensive plan for collecting relevant data, encompassing primary energy sources, conversion technologies, emissions data, and other important variables.
- Utilize a diverse range of sources, including official energy databases, research publications, and industry reports, ensuring the accuracy and reliability of the

collected information.

4.1.2 Parameterization of the Model:

- Employ the openMASTER model's modular and user-friendly format to facilitate parameterization.
- Define and configure the sets and parameters that constitute the model, ensuring accuracy and consistency.
- Determine the time horizon and temporal resolution, incorporating time slices representing seasons, days, and hours for dynamic modeling.
- Establish relationships between interconnected sets to prevent inconsistent flows, with a focus on primary energy vectors, conversion technologies, and energy flows.
- Develop subsets to represent smaller groups of elements, such as renewable energy vectors, and ensure their consistent definition.

4.2 Study Case Application (2nd & 3rd Month)

4.2.1 Selection of Specific Cases:

- Identify specific cases within the Spanish energy system for applying the openMASTER model.
- Consider diverse scenarios, including varying primary energy sources, technological configurations, and policy contexts, to capture a holistic representation of the energy landscape.
- Ensure that selected cases are representative and cover a spectrum of relevant variables for a comprehensive analysis.

4.2.2 Analysis of Results and Model Performance:

- Implement the openMASTER model on selected cases and run simulations for energy optimization.
- Analyze the results, focusing on emissions profiles, energy system dynamics, and the performance of renewable integration and storage technologies.
- Evaluate the model's robustness and accuracy in simulating real-world scenarios.
- Identify any limitations or areas for refinement in the openMASTER model.

4.3 Results Analysis and Document Elaboration (4rth & 5th Month)

4.3.1 Interpretation of Findings:

- Conduct a detailed analysis and interpretation of the findings from the study cases.
- Explore the implications of different scenarios on emissions reduction, renewable integration, and overall energy system performance.
- Identify patterns, trends, and critical insights derived from the openMASTER model simulations.

4.3.2 Final Document Preparation:

- Compile the research outcomes, analysis, and interpretations into a comprehensive final document.
- Structure the document to include an introduction, methodology, results, discussion, conclusions, and recommendations.
- Provide a synthesis of key findings, emphasizing their relevance to the broader goals of achieving a net-zero Spanish energy system.

- Formulate clear and actionable conclusions and recommendations based on the research outcomes.
- This methodology ensures a systematic and rigorous approach to the assessment of greenhouse gas emissions and other pollutants in the Spanish energy system using the openMASTER model. It combines robust data collection, model parameterization, case-specific applications, and thorough results analysis to contribute valuable insights to the field of sustainable energy.

5. *WORK PLAN*

The work plan outlines a structured timeline for the execution of the master thesis, spanning five months. Each phase of the research, from data collection to document elaboration, is allocated specific timeframes to ensure a systematic and efficient progression. The plan encompasses key activities, milestones, and deliverables, facilitating a well-organized and timely completion of the research objectives.

5.1 Introduction

The work plan is designed to provide a clear roadmap for the execution of the master thesis on assessing greenhouse gas emissions in the context of achieving a net-zero Spanish energy system. This plan reflects a systematic approach, allocating time for data collection and parameterization, application of the openMASTER model to specific cases, and thorough analysis of results leading to the final document elaboration. Each phase of the plan is meticulously structured to ensure a comprehensive and timely exploration of the research objectives.

5.2 Work Plan Table

Month	Phase	Activities	Milestones	Deliverables
Month 1	Data Collection and Parameterization	- Develop data collection plan -Collect relevant energy system data - Parameterize openMASTER model based on collected data	- Completed data collection plan - Acquired and organized energy system data - Configured openMASTER model parameters	Initial dataset, Configured openMASTER model
Month 2 & 3	Study Case Application	- Select specific cases for openMASTER application - Run simulations and analyze results - Evaluate model performance	- Identified and selected representative study cases - Conducted openMASTER simulations - Analyzed results and assessed model performance	Simulated case results, Model performance evaluation
Month 4 & 5	Results Analysis	- Interpret findings	- Comprehensive	Final document

	and Document Elaboration	from study cases - Compile and structure research outcomes -Formulate conclusions and recommendations	interpretation of study case findings - Structured and compiled final document - Formulated clear and actionable conclusions and recommendations	with analysis, Conclusions and recommendations