

Expert-Driven Assessment of Sustainability for Electricity Market Changes

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Abstract—Securing sustainable power systems requires understanding how regulatory frameworks and technological advancements interact with economic, social, environmental, and legal sustainability aspects. This study explores these relationships by analyzing expert opinions from academia, industry, and policy sectors from Europe and the Americas. The interview data is used to generate concept maps, revealing key interrelations and externalities within electricity markets. Additionally, Natural Language Processing (NLP) techniques, including cosine similarity metrics, quantifies the alignment between expert discussions and Key Performance Indicators (KPIs) for smart markets. The findings highlight the need to select specific KPIs for each sustainability dimension, including environmental impact, economic efficiency, social equity, and security of supply. This research demonstrates the value of integrating expert insights with advanced analytical methods to assess market transformations and support sustainable policy decisions.

Index Terms—Electricity Market, Natural Language Processing, Power Markets, Smart Grids, Sustainable Development.

I. INTRODUCTION

The lack of a standardized method for assessing the sustainability of different electricity market designs presents a significant challenge today. International organizations such as SEE4all, the World Bank, and the European Union (EU) have proposed methods to measure specific sustainability goals. However, these frameworks typically do not account for the impact of market design on achieving these objectives.

Modifications to electricity market rules must be evaluated in the context of their alignment with sustainability objectives, particularly in the transition to a sustainable power system. However, there are limited studies that has assessed the sustainability of electricity markets [1]. One of the main challenges is the variation in sustainability considerations across different countries, and the necessity to establish regulatory frameworks that are grounded in sustainability principles.

Traditionally, the assessment of electricity markets has primarily focused on economic factors, often neglecting the environmental, social, and legal dimensions. Some research has

explored specific aspects of these dimensions. For example, the social impact of green energy adoption [2], energy import dependency, and supply security have been examined, with relevant indicators proposed for their evaluation [3]. Other studies have delved into the interdisciplinary nexus between the sharing economy and sustainability [4]. In particular, [5] proposed KPIs for assessing flexibility markets in relation to sustainability aspects through a bibliometric approach. However, further research is needed to identify the qualitative interactions in the market dynamic.

In addition, electricity markets are inherently complex, necessitating qualitative assessment. A qualitative electricity market assessment is usually performed by experts. Semi structured interviews are applied to gain knowledge from experts and understand the interactions among market concepts. Semi-structured interviews are defined as an "interview with the purpose of obtaining descriptions of the real-life world and interpreting the meaning of the described phenomena" [6]. In addition, with the knowledge of the experts it is possible to identify the most appropriate indicators to evaluate the comprehensive sustainability of electricity markets.

Natural Language Processing (NLP) libraries are useful tools for data summarization and various aspects of data processing [7]. These tools are critical for developing mind maps that connect concepts expressed in semi-structured interviews. Additionally, data mining serves as an information extraction technique that is particularly effective for uncovering hidden knowledge [8]. These techniques can be employed to cluster terms and construct mind maps that represent the relationships between concepts identified by each interviewee.

This study explores from experts interviews how electricity market changes can be assessed. NLP and concept mapping techniques are employed to understand relationships among main topics of the interview. Moreover, this research quantifies the alignment between expert discussions and KPIs for smart markets proposed in [5]. In addition, it uses cosine similarity

to measures the similarity between two vectors in terms of their subject matter [9]. In this research the similarity between the indicators for different market, changes considering, the interview corpus.

The organization of the paper proceeds as follows. Section-II describes the methodology and Section-III discusses the interview processing results. Use cases are explained in Section-IV with discussion and concluding remarks are given in Section-V and Section-VI.

II. METHODOLOGY

To obtain the results presented in this paper two main process are conducted: the first one is the elaboration of semi-structure interviews with key stakeholders. The second process is extracting knowledge from those interviews with the objective to assess sustainability in electricity markets. The following subsections explain each of these processes.

A. Semi-Structured Interviews

Semi-structured interviews provide an exceptional platform for exploring the complexities of human perception and experience. The interviews with key stakeholders served as a central methodological approach to evaluate the main concepts with respect to electricity markets and smart grids. Each interviewee represents a unique stakeholder sector, encompassing energy policymakers, academia, and industry representatives, both from Germany and Panama. Moreover, central to this endeavor are the contributions of regional consultants, whose extensive experience spanned over 15 years in both the Latin American, North America, and European energy markets. Their insights encompassed a comprehensive overview of current practices in the implementation of new market regulations, its challenges, and recommendations for improvement based on international experiences.

The open-source text analysis software *QualCoder 3.4*, and *VoyantServer 2.6.10* are suitable to conduct a qualitative examination of interview transcripts [10]. All interviews are coded to categorize topics and statements, which supported the selection of main concept and terms. Since some topics are related to each other, the code allows to link relationships among the concepts [11]. For each interview a concept map is created. Concept mapping is a systematic approach to visually organize and analyze interview data by transforming qualitative insights into structured and interconnected themes.

B. Data Mining and NLP for Interview Processing

Content analysis and data mining are utilized to deduce patterns and knowledge from the interview data, such as recurring themes, common trends, and underlying relationships. These techniques enabled the extraction of valuable insights into the perspectives and experiences shared by the interviewees regarding the electricity market and its sustainability aspects.

Text mining generally refers to the process of extracting interesting and non trivial patterns of knowledge from text [12]. A comprehensive content analysis is conducted on the entire corpus of interviews to discern about topics. In addition,

the corpus of each interview is processed in Python, utilizing NLP techniques to perform semantic analysis and identify patterns and relationships within the text and the main clusters extracted from the interview codification. The NLP Python library is also used to token each interview corpus and support the extraction of relationships.

All the relationships are graphically presented using concept mapping techniques. Concept mapping is an additional graphical tool to gain knowledge that supports conceptual thinking and is used to conduct research [13]. It has been applied to encourage learning, present findings, and study interrelationships, among others [14]. In this study, this tool is employed to summarize each interview, allowing a visual representation of the main ideas expressed by each interviewee. The similarities, differences and the relationships between the concepts expressed by each interviewee are emphasized. The final outcome is the creation of several concept maps that support the relationship between the sustainability aspects and electricity market assessment.

III. INTERVIEW PROCESSING RESULTS

The analysis conducted for each interviewee results in a unified mind map accessible in the git repository ¹. The Figure 1, illustrates as an example of the main topics discussed for evaluating social and environmental aspects in electricity markets. For example, regarding social aspect the interviewees discussed how smart grid technologies could support changes in the market by adding grid visibility need and tariff opportunities aiming to incentivize new figures and competitions from the customer side.

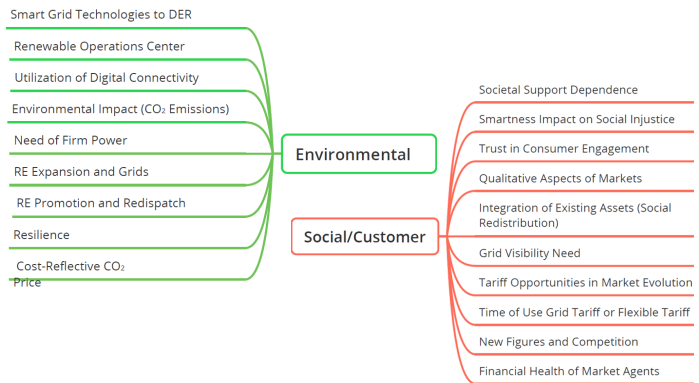


Figure 1. Main Environmental and Social Concerns According to the Interviewees.

From figure 1 it is observed that the interviewees are interested the utilization of digital connectivity led to the creation of renewable energy operation centers that promotes the renewable energy utilization. Moreover, it was mentioned, the need of increase resilience and add a cost reflective CO_2 price in the market as part of the environmental aspects. This last idea, supports the proliferation of clean energy technologies but at the same time can hinder the economic

¹https://gitlab.com/indicators_KPI/interviews_corpus/-/tree/main

aspect regarding market competitiveness, specially in regional markets.

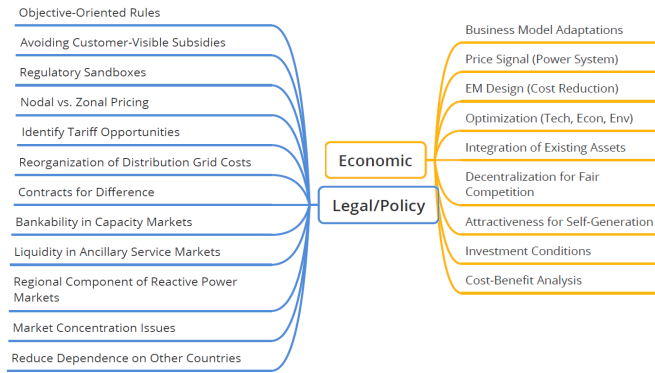


Figure 2. Main Legal/Policy and Economic Concerns According to the Interviewees.

Figure 2 depicts the main market topics that can be related with the economic and legal sustainability aspects. The economic aspects are related to the price, investment conditions and competition. The legal/policy aspects are market power regulations, decisions regarding subsidies, nodal and zonal pricing, regional components and security of supply.

Similarly, concept maps are created using the codification of the interview and NLP techniques. For example, it is understood that the consideration of rapid responses and redispatch measures to advance renewable energy initiatives, contingent upon the dimensions of the market. One major concern is the pivotal role of market size, that emerges as a significant impediment to overcome during the implementation of novel regulatory frameworks. This is represented in the mind map shown in Figure 3.

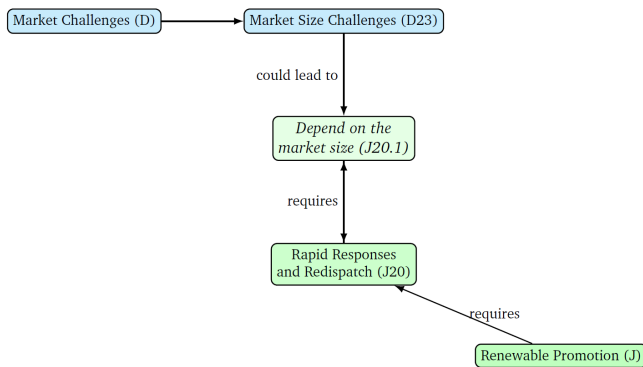


Figure 3. Market Size and Renewable Promotion.

Similarly in Figure 4, it is shown that the sustainable power system could bring social benefits to the customer and therefore, the public acceptance of a new implementation can be obtained. It can also be seen that that public acceptance needs to consider the economic feasibility and the technical viability of a new implementation.

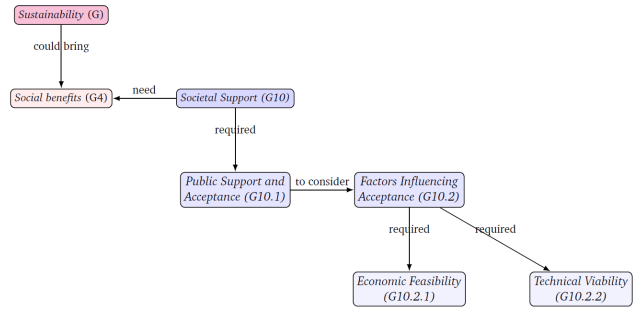


Figure 4. Factors Influencing Public Support and Acceptance.

IV. USE CASE

The relationships among words and topics were analyzed to extract a list of common KPIs and themes that can be utilized to evaluate impacts on sustainability dimensions, considering potential changes in market designs. The list of KPIs proposed in [5] was utilized to find indicators suitable for assessing experts' concerns. Among the interview corpus, topics about implementing payment mechanisms for flexibility markets in distribution systems were discussed. Therefore, the use case considering two payment mechanisms are:

- A Cost-Based Approach: Similar to redispatch concepts, in which payment for the flexibility is based on a cost value. Usually a fix amount calculated by the regulatory authority.
- Bidding mechanisms: Voluntary participation of Distributed Energy Resources (DER) units in the market. It is considered that DER are willing to alter its energy generation or consumption if a market is created. To participate, each DER provides an offer. The offer consist of a quantity, price and time interval.

The cosine similarity was calculated to understand the correlation among KPIs and interviewees concerns group by payment mechanisms. Figure 5 depicts the correlation between the KPIs and the statements for each payment mechanisms. The cosine similarity scores are represented by the varying shades of color. High cosine similarity scores (darker colors) represent stronger relation.

For bidding payment mechanisms KPIs such as: "Number of Participants in Auctions" and "Incentive-Based Demand Response" showed a strong cosine similarity. For cost-based markets KPIs with strong cosine similarity are *Prosumer Engagement*, *Real-Time Data-Customer to DSO* and *Cost Management Optimization*. A total of 81.2% of the identified KPIs could be used to assess aspects mentioned by stakeholders.

V. DISCUSSION

The analysis revealed that some indicators are common across multiple market mechanisms, demonstrating their broad applicability. The strongly related KPIs show its capability to assess specific market aspects. For instance, statements

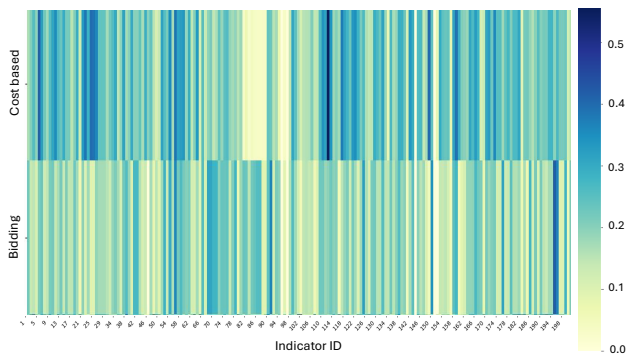


Figure 5. Cosine Similarity Between KPIs and the Interviewee Statements per Payment Mechanisms.

such as "Decreasing CO2 Emissions" and "Renewable Energy Management" are relevant to various market mechanisms, highlighting the importance of the environmental dimension of sustainability.

Some concepts expressed in several mind maps are not directly represented by indicators but are essential in understanding the context and the major concerns in the evaluations of changes in electricity markets. Some examples of these are concepts like "The Aggregator Roles and the Customer Inclusion", "Institutionalization", and "Data Volume and the Needs of Control Centers". In these cases, it is proposed to use specific indicators that considers the relationships among these concepts to others with the use of the concept maps.

An important parallel aspect is that economic aspects extracted from the interviews, such as "Aims for Optimization and Economic Efficiency" and "Financial Health of Market Agents", are highlighted across different market mechanisms, emphasizing their centrality to evaluating market efficiency and stability.

Similarly, social indicators, such as "Influence of Customers" and "Social Responsibility", are critical aspects in assessing the impact of market rules on consumer engagement and societal well-being. Moreover, for any type of bidding mechanisms, it is necessary to evaluate the participation of actors in different markets. This can be implemented through a measure of performance diversity. Such indicators can be applied to analyze the behavior of actors who place bids within a specific market. Figure 6 and Figure 7 summarize the main concerns regarding the sustainability aspect.

VI. CONCLUSION

This study conducted an expert-driven assessment of sustainability for electricity market changes using interviews. The evaluation of the main interview topics show that, when evaluating market changes, it is crucial to address externalities and implications for other sustainability dimensions. This involves analyzing the broader impacts of regulatory changes on social, economic, and environmental aspects using NLP and data mining techniques. The advantages of using these techniques, facilitates the identification and analysis of relationships among KPIs and payment mechanisms in a flexibility

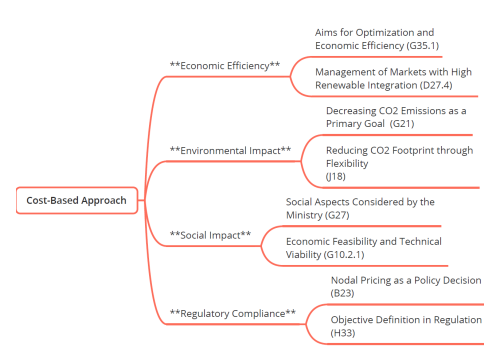


Figure 6. Cost Based Payment Mechanism and the Main Topics per KPI Considering Sustainability Aspects.

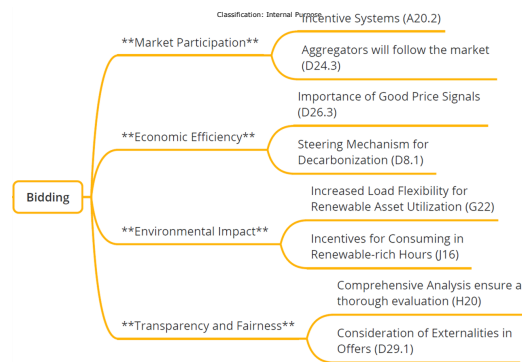


Figure 7. Bidding as Payment Mechanism and the Main Topics per KPI Considering Sustainability Aspects.

market. The use case explains how the main interviewee topics support the selection of indicators for regulatory changes. This research contributes to the development of sustainable and efficient mechanisms to evaluate electricity markets, which align with regulatory objectives and societal needs.

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