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Renewable Energy Policy Trends in the European Union: Insights from a Text Mining Analysis

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***Abstract*—The European Union's renewable energy transition was affected by significant geopolitical challenges recently and the necessary changes in strategic plans were adopted. This study reflects how likely these changes will lead to the consistent development of energy systems taking into consideration all stages of the energy supply chain. Through the extraction and preprocessing of text from National Energy and Climate Plans (NECPs), along with frequency analysis to identify key signals and the application of k-means clustering to categorise countries based on their renewable energy strategies, this study finds substantial variations in the approaches of the EU countries towards renewable energy development, particularly emphasising different segments of the supply chain. The findings underscore the importance of holistic, supply chain-inclusive strategies to achieve the EU's renewable energy and climate goals.**

***Keywords*—renewable energy, supply chain, generation, transmission, distribution, storage, supply, clustering.**

I. INTRODUCTION

Adopted by the EU countries in 2019 the National Energy and Climate Plans (NECPs) legally bound national goals set by Directive 2009/28/EC [1] and revised Directive 2018/2001/EU [2] enabling progress toward cleaner energy and a greener future. The economic advantages of implementing National Energy and Climate Plans (NECPs) by the EU countries are significant. These strategies play a crucial role in stimulating investment, driving economic growth, and generating employment opportunities, particularly within the renewable energy sectors. By modernizing energy systems, they also facilitate a reduction in energy costs and enhance the EU's global competitiveness. The stable policy environment provided by the NECPs is vital for fostering innovation, enabling the EU to maintain its leadership in clean energy technologies.

However, recent geopolitical upheavals, particularly the Russian invasion of Ukraine, have significantly impacted the EU's energy policy landscape.

In the immediate aftermath of the invasion, European countries moved swiftly to secure alternative energy sources to replace Russian oil and gas. This urgency led to temporary measures such as extending the life of coal-fired power plants and increasing liquefied natural gas imports [3]. While necessary for energy security, these measures put at risk short-term climate goals. Despite these setbacks, the crisis has accelerated investments in renewable energy infrastructure and energy efficiency measures, underscoring the EU's long-term commitment to the Green Deal objectives.

Experts [4-6] consider the impact of the war as presenting new challenges and opportunities. By the end of 2023, renewable energy exceeded all other energy sources in the power generation structure for the first time in five years, accounting for more than 40% of all electricity production. It is noteworthy that following the adoption of NECPs, the development of renewable energy sources (RES) saw an increase of approximately 9% by the end of 2020. However, this momentum slowed significantly, with growth rates declining to 0.8% in 2021 compared to 2020, and to 1.5% in 2022 compared to 2021. It was not until 2023 that RES experienced a significant increase, achieving a rapid growth rate of 15%. As illustrated in Fig. 1, there was no marked increase in the RES share of total electric production nor a corresponding decrease in fossil fuel use until a notable acceleration of 9% in renewable energy by 2023.

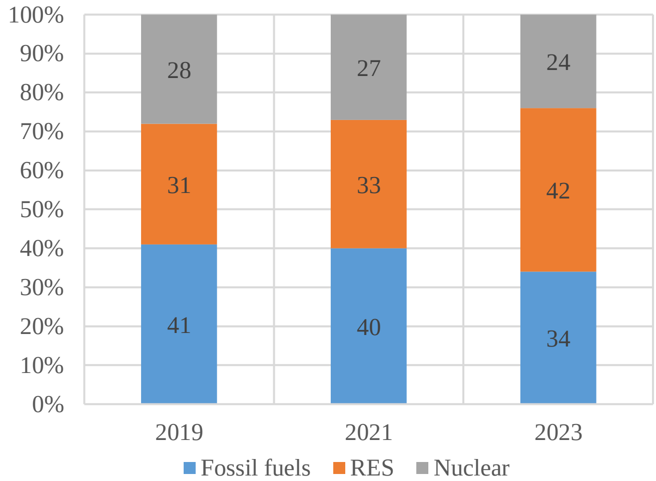

Fig. 1. Share of energy sources in total electricity production in EU countries, %

This trend supports the hypothesis that the war in Ukraine, by causing an energy crisis, has accelerated the transition to renewable energy.

Another critical issue is whether the NECPs address the development of a sustainable renewable energy system. It is well-known that clean energy requires significant changes across the entire supply chain, from energy generation to transmission, distribution, storage, and supply. Therefore, evaluating whether these strategies comprehensively consider these factors and provide a consistent pathway toward a clean energy future is essential.

This paper aims to provide deeper insights into the evolving trends in the EU renewable energy policy by leveraging text mining analysis, helping to understand the complex interplay between policy design and renewable energy development.

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II. Review of the State-of-the-Art Research

This section of the paper provides a comprehensive analysis of the recently published research papers on the topics related to the evaluation of the NECPs followed by applying novel analytical methodology to these energy documents. To demonstrate the relevance of the research connected to the NECPs this paper analyses the data extracted from the Scopus database. Fig. 2 illustrates the increasing number of recently published papers obtained using ‘national AND energy AND climate AND plan’ search criterion over 2019-2023.

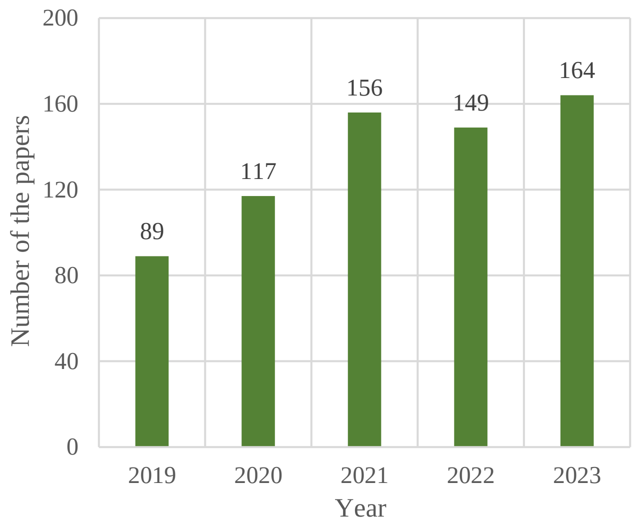

Fig. 2. Number of the recently published papers on the NECP-related topic indexed by the Scopus database

Going into the details, the research paper [7] employs non-trivial Börzel’s theoretical framework on Europeanisation to examine the responses, strategies, and compliance of the EU countries to the Green Deal. According to the methodology, the EU countries are classified into 3 groups by the types of strategies: (i) actively pushing policies, (ii) blocking or delaying them and (iii) neither systematically pushing policies nor trying to block them. The authors observed a significant variation in the strategies of the EU countries, with some transitioning from one approach to another. These shifts in classification are attributed to the different response paces of the stakeholders involved in environment, climate, and energy within the internal policy contexts of the EU countries. The paper concludes by discussing the NECPs, examining the EU countries responses and compliance with the discussed new framework, and highlighting several challenges.

Authors of the research paper [8], by collecting and categorising a total of 230 sufficiency-related policy measures, established significant differences across countries. According to the paper’s conclusions, the types of sufficiency policy instruments vary considerably from sector to sector, while the regulatory instruments currently play a minor role in sufficiency policy. As the main methods of the research authors used categorisation developed on the three classes according to their sufficiency.

Some research papers as [9] and [10] employ analytical methods to assess NECPs, focusing on the transition to renewable energy sources. Both papers concentrate on the critical evaluation of climate plans highlighting the absence of risk analysis and alternative scenarios.

As one can see from this overview, there is increasing attention in the literature to the evaluation of the NECPs. Our work contributes to this literature by utilising a novel hybrid approach comprised of text mining and clustering analysis. In the next section, we describe the details of the methodology and the data we used in this research.

III. Methodology and Data for the Research

Our main objective was to assess the EU countries’ NECPs in terms of their consistency of the energy supply chains with the EU general energy and climate Directives. To achieve this objective, we applied a combination of advanced techniques for preprocessing NECPs.

First, we carry out a textual analysis of the NECPs using the Natural Language Processing (NLP) approach. The LDA (Latent Dirichlet Allocation) model is implemented to receive a more advanced understanding obtained from both general analysis and the examination of predefined keywords. Second, in each stage, the k-means method is applied to reveal clustering similarities for the NECPs of the EU countries. Further details of the workflow are provided below.

The flowchart in Fig. 3 visualises the entire chain of the analysis allowing the reader to follow the sequence of steps in our research approach.

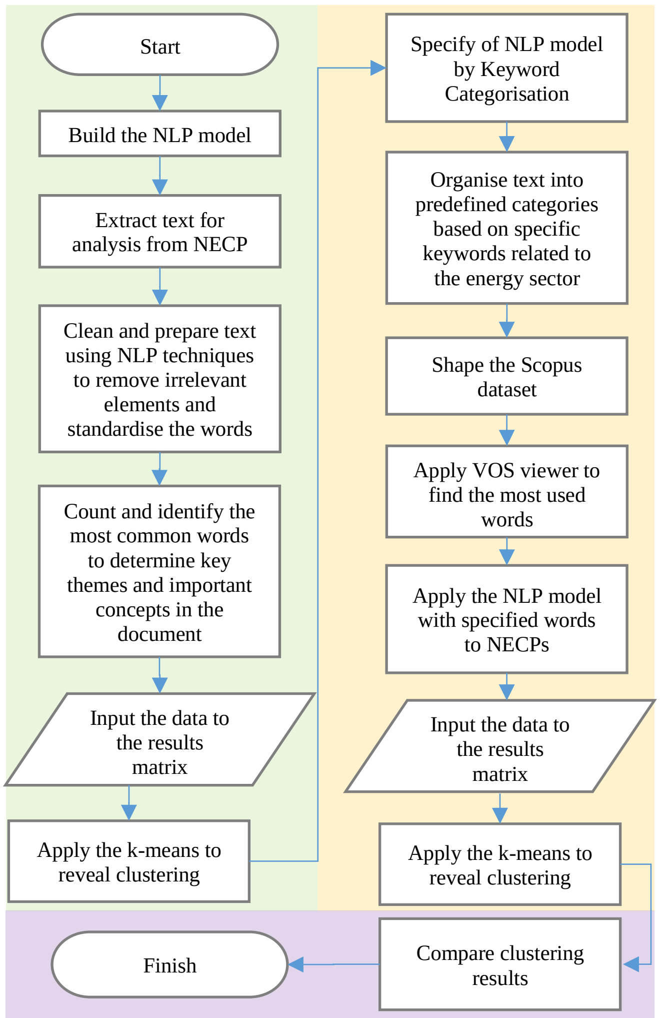

Fig. 3. The flowchart representing the algorithm applied for the research in this paper with the highlighted stages

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A. Text mining

Working with textual information and evaluating text documents is always a challenging task. The nature of this lies in the need to deal with a large amount of non-structured information, screening the context of the source, following the structure etc. To address the complexity of the text assessment numerous statistical and machine-learning techniques have been developed recently. Generally, the assembly of these approaches is called text mining and among them, there are specific techniques designed to clean and visualise the text, provide statistical analysis, generate the text etc. Existing techniques are represented through the libraries and toolboxes for Python, R and MATLAB.

We used the text mining approach to perform an analysis of the NECPs presented in this paper. In particular, one of the methods used was an NLP model (in our case, specifically Latent Dirichlet Allocation (LDA) model), which operates by transforming and understanding human language through several stages. Initially, the text undergoes preprocessing, including tokenization, normalization, and stop word removal, to convert it into a standardised format and create organised corpus of the data for further analysis. Then, the LDA model is trained to identify the topics. During model training, a text is transformed into numerical embeddings and processed through neural networks, which learn to predict outcomes by adjusting their parameters. Once trained, such models can perform tasks such as text classification, sentiment analysis, and machine translation by encoding input text, making predictions, and decoding the output. In this study, we analyse the outcomes of the model's application to identify potential approaches for enhancing its performance.

B. VOS viewer tool

To show the connections between the most used words, which appear in the papers' titles and abstracts VOS viewer tool was used. VOS viewer is a software tool for creating connection maps based on network data that is already available and for visualising and exploring these maps [11]. Practical utilisation of the VOS viewer tool was illustrated in an application to sources related to resilience and Net Zero [12]. In this paper, we utilise the VOS viewer tool to create connections and analyse the keywords related to every part of the power supply chain, including generation, transmission, distribution, storage and supply. Specifically, the data requests were narrowed to 'renewable energy generation', 'renewable energy transmission', 'renewable energy distribution', 'renewable energy storage', and 'renewable energy supply'. All the data analysed were extracted from the Scopus database with the 2022-2023 period taken.

C. K-means clustering

K-means clustering is an unsupervised machine learning algorithm used to partition a dataset into distinct groups, or clusters, based on feature similarity. The algorithm starts by randomly initialising *k* centroids, where *k* is the number of desired clusters. Each data point is then assigned to the nearest centroid, forming initial clusters. The centroids are recalculated as the meaning of all data points within each cluster. This process of assignment and centroid recalculation repeats iteratively until the centroids stabilise, minimising the variance within clusters and maximising the variance between them. K-means is widely used across many economic tasks such as market segmentation and anomaly detection due to its simplicity and efficiency. In this paper, this technique allowed the classification of the EU countries into clusters with different approaches to the energy supply chain according to the statistical information received from the text mining approach.

For assessing the clusters k-means utilises the distance between data points and centroids or the Euclidean distance formula [13]. The Euclidean distance between a data point $x_i = (x_{i1}, x_{i2}, \dots\ x_{xn})$ and a centroid $\mu_i = (\mu_{j1}, \mu_{j2}, \dots\ \mu_{jn})$ is calculated as:

$$d(x_i, \mu_j) = \sqrt{\sum_{k=1}^{n}(x_{ik} - \mu_{jk})} \qquad (1)$$

However, the k-means algorithm requires the user to specify the number of clusters in advance and can be sensitive to the initial placement of centroids. In this paper, the Sturges' rule [14] is utilised to define the optimal number of clusters:

$$n = 1 + 3.332 \log N \qquad (2)$$

where n is the number of clusters and N is the number of observations. According to the calculations for this research, the optimal number of clusters is equal to 6.

D. Software and hardware used

For the investigations, we used Python and MATLAB as the software and personal computer with the following characteristics as the hardware: Intel Core i7-11370H, 8GB memory RTX 3060.

IV. Empirical Results

In the first step, we utilise the NLP model to analyse the NECP strategies of the EU countries and understand how likely the documents contain a pattern for considering the development of the energy system in a comprehensive manner, taking into account all segments of the energy supply chain.

We considered the latest published versions of NECPs. It must be noted that most of the EU countries provided updated 2023 NECP Drafts. Denmark, Finland, Italy, Netherlands, and Sweden provided the final updated NECP (submitted in 2024) and Austria hasn't offered any updates yet since 2019, and so its 2019 NECP was included in the analysis.

We conducted a frequency analysis to identify key themes and significant concepts within each NECP. Subsequently, we evaluated the relationships between the documents through cluster analysis, the results of which are illustrated in Fig. 4.

Cluster 1 represents such countries as Greece, Latvia, Poland, and Slovenia, which have moderate key themes frequencies across various energy-related terms. Countries like Greece and Poland show a balanced yet moderate emphasis on renewable energy key themes, indicating steady but less intense strategies. As for the supply chain, we could not identify any common pattern because of the significant heterogeneities among these countries. Specifically, Greece has more focus on storage, Poland – on generation and supply, and Slovenia – on transmission).

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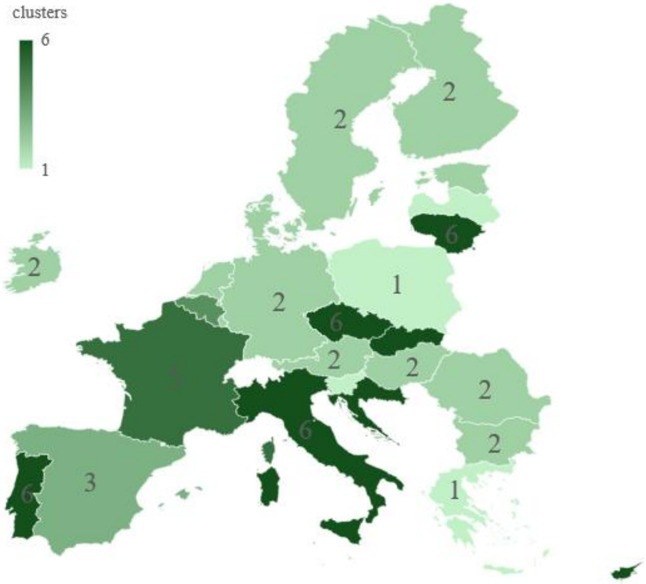

Fig. 4. Clustering of the EU countries by NECP's key themes

Cluster 2 represents most of the EU countries: Austria, Bulgaria, Denmark, Estonia, Finland, Germany, Hungary, the Republic of Ireland, Luxembourg, Malta, the Netherlands, Romania, and Sweden. A balanced and consistent emphasis on various energy-related key themes has been observed, indicating a robust strategic framework in terms of renewable energy. However, within this cluster, we can identify more specific subgroups of countries:

- Austria, Finland, Romania, and Sweden do not highlight supply chain stages.
- Estonia, Germany, Hungary, the Republic of Ireland, and the Netherlands demonstrate an emphasis on the supply stage of the chain.
- Denmark and Malta demonstrate an accent on generation and supply stages.
- Bulgaria and Luxembourg demonstrate focus only on one certain stage (Bulgaria on transmission, Luxembourg on generation).

Cluster 3 consists only of Spain. It can be explained by exceptionally high key theme frequencies, indicating a detailed and extensive focus on renewable energy strategy, as well as the strongest accent on the generation stage.

Cluster 4 also consists of one county – Belgium. Similar to Spain, Belgium stands alone in this cluster with high key theme frequencies across various categories. However, there are no noticeable signals specifically about the supply chain.

France represents Cluster 5 showing moderate frequencies in key themes, indicating a focused yet balanced approach towards renewable energy and climate change, but without noticeable signals about the supply chain.

Cluster 6 consists of such countries as Croatia, Cyprus, the Czech Republic, Italy, Lithuania, Portugal, and Slovakia. These countries represent a diverse range of high frequencies in various key themes and some heterogeneous signals about the supply chain's transmission (Croatia and the Czech Republic), supply (Lithuania), and both generation and supply (Lithuania) stages.

For a deeper understanding of whether the EU countries comprehensively consider the whole energy system and the changes that need to be applied, we analyse the NECPs by predefined categories based on specific keywords related to the energy sector supply chain: generation, transmission, distribution, storage, and supply. For defining the keywords for each supply chain stage, we used Scopus dataset and VOS viewer tool described in the methodology section. After the identification of sets of keywords by each category they were added to the NLP model before repeating clustering analysis. The results of clustering can be seen in Fig. 5.

It must be mentioned that keywords associated with the generation stage of the supply chain dominate other categories across all countries. Therefore, we consider the variations observed in the clustering results to be significant.

We can see that Cluster 1 is represented by such countries as Denmark, Netherlands, Portugal, Austria, France, Hungary, Romania, Slovenia, Cyprus, Finland, Germany, Greece, the Republic of Ireland, Luxembourg, Poland, Sweden, Estonia, and Malta. Generally, these countries have moderate to high counts across all categories. They show a balanced focus on various aspects of renewable energy, indicating comprehensive strategies with a strong emphasis on energy production.

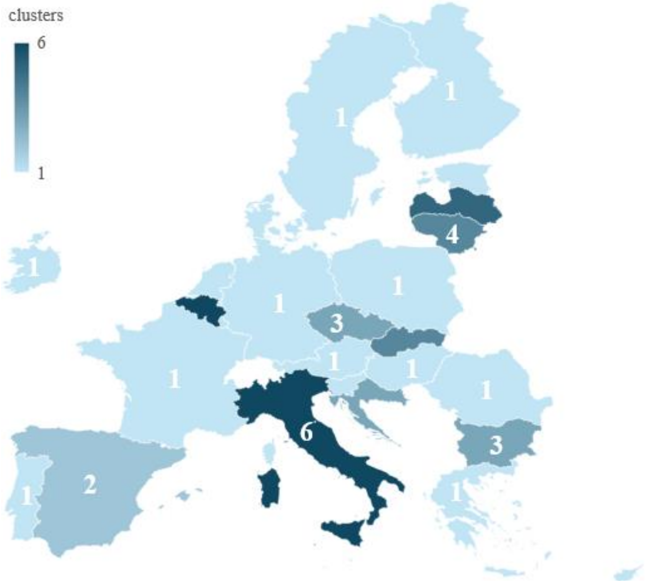

Fig. 5. Clustering of EU countries by NECP'S key supply chain categories

Spain stands alone in Cluster 2, with exceptionally high counts in generation, distribution, storage, and supply categories but especially there is a significant focus on renewable energy generation and storage.

Cluster 3 is represented by such countries as the Czech Republic, Bulgaria, and Croatia. The specificity of this cluster lies in high counts in the generation and transmission categories and substantial counts in other categories. Thus, we can assume that these countries are mainly focused on the gradual development of infrastructure for renewable energy.

Slovakia and Lithuania represent Cluster 4 and can be characterised by showing particularly high counts in generation and supply. Both countries might demonstrate their efforts to enhance renewable energy infrastructure and supply chains.

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Cluster 5 is represented by Latvia with comparatively low counts in almost all categories, showing minimal activity in renewable energy keywords. We can conclude that this indicates limited progress or insufficient focus on renewable energy initiatives compared to other clusters.

Cluster 6 is represented by Belgium and Italy. These countries have high counts in all categories, especially in generation and storage. Thus, this cluster is similar to Cluster 1 in demonstrating comprehensive and significant strategies for renewable energy development.

In summary, the results of both clustering approaches reveal a more profound understanding of the differences across the ways NECPs of the EU countries consider the whole energy supply chain, as shown in Table 1.

TABLE I. MATRIX OF THE NECP CLUSTERING RESULTS

Country	**Generation**	**Transmission**	**Distribution**	**Storage**	**Supply**
Denmark	xx	x	x	x	xx
Netherlands	xx	x	x	x	xx
Slovakia	xx	x	x	x	xx
Poland	xx	x	x	x	xx
Malta	xx	x	x	x	xx
Estonia	x	x	x	x	xx
Germany	x	x	x	x	xx
Hungary	x	x	x	x	xx
The Republic of Ireland	x	x	x	x	xx
Lithuania	x	x	x	x	xx
Luxemburg	xx	x	x	x	x
Spain	xx	x	x	x	x
Bulgaria	x	xx	x	x	x
The Czech Republic	x	xx	x	x	x
Croatia	x	xx	x	x	x
Slovenia	x	xx	x	x	x
Greece	x	x	x	xx	x
Belgium	x	x	x	x	x
Cyprus	x	x	x	x	x
France	x	x	x	x	x
Italy	x	x	x	x	x
Portugal	x	x	x	x	x
Austria	x	x	x	x	x
Finland	x	x	x	x	x
Romania	x	x	x	x	x
Sweden	x	x	x	x	x
Latvia	x	x	x		x

The comparison of the two clustering approaches has enabled us to develop a more coherent method for grouping the EU countries based on their intentions to build a renewable energy system, considering the supply chain approach.

NECPs of countries like Denmark, the Netherlands, Slovakia, Poland, and Malta reveal consistent strategies for developing renewable energy systems with greater attention to generation and supply stages.

Most of the other countries have differences in clustering which are related to the attention to different stages of the energy supply chain: Estonia, Germany, Hungary, the Republic of Ireland, and Lithuania are oriented more on the supply stage, Luxemburg and Spain – on the generation stage, Bulgaria, the Czech Republic, Croatia, Slovenia – on the transmission stage, and Greece – on the storage stage.

It must be mentioned that Spain was placed in a separate unique single-element cluster by both clustering approaches, which can indicate the distinct strategic focuses and might be considered as a case study for further analysis.

A more moderate but still balanced approach can be seen in the NECPs of Belgium, Cyprus, France, Italy, Portugal, Austria, Finland, Romania, and Sweden.

Finally, the NECP of Latvia demonstrates the most inconsistent approach to developing renewable energy systems, as it does not encompass the entire energy supply chain. This inconsistency may affect not only the efficiency and robustness of renewable energy system development but also the broader pan-European system and market. Consequently, it requires consideration as a case study for further analysis.

The classification of the EU countries based on their approaches to developing renewable energy systems, considering the stages of the energy supply chain, allows the estimation of subsequent effects associated with the intensified development of specific industries focused on particular supply chain stages. This valuable information can facilitate targeted collaborations between the core and periphery countries in the EU. Furthermore, this also enables estimation of the secondary effects on the resulting employment structure and its anticipated changes.

V. CONCLUSIONS

In this study, based on the text mining methodology and using a combined comparative approach to evaluate the results, we investigated how comprehensive the EU NECPs are from the perspective of the energy value chain, which is the foundation for the development of renewable energy in the long term. Firstly, by using the NLP model for text analysis and refining the analysis parameters, we were able to identify clear signals of renewable energy value chain development in each individual EU country. Secondly, by clustering countries according to the identified common features and comparing the results, we identified both successful and problematic cases, which will ultimately help to assess potential growth centres for the industry and identify the pathways for efficient industrial collaboration and its effect on the labour market.

One possible avenue for further research is a detailed qualitative analysis of contextual differences between countries to identify the structural reasons behind the divergence in the EU countries' approach to the renewable energy value chain.

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