Wind and Solar Power Generation Perceptions: Towards a Sustainable Energy System in Portugal's Centro Region

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Abstract **- New investments in wind and solar power are key to advancing the energy transition and reducing greenhouse gas emissions. While these technologies bring global benefits, they also generate local externalities. The R3EA Project, within which this study is conducted, focuses on assessing these externalities in Portugal's Centro Region, where RES infrastructure is highly concentrated. Given the scarcity of studies adopting a holistic perspective, this work aims to address this gap by utilizing systems thinking. It involves the construction of a systemigram, where the system represents the relationship between new investments in wind and solar energy, the achievement of a sustainable energy system, and all the factors and stakeholders that influence it. In this case, the analysis is developed to understand, based on the literature, the impact of social acceptance on investments in wind and solar technologies, the importance of energy justice, and the role of local authorities.**

Index Terms **- Local Authorities, Social Acceptance, Wind Power, Solar Power, Systemigram**

I. Introduction

Portugal is making significant progress in the transition to sustainable energy, with a focus on integrating renewable sources into its electricity system [1]. Hydropower, wind, and solar energy comprise 61% of the country's total power generation [2], [3]. In addition, Portugal has outlined an ambitious strategy for carbon neutrality through its Carbon Neutrality Roadmap 2050 (RNC2050), setting a target to cut greenhouse gas emissions by over 85% from 2005 levels [4].

In line with its obligations under the Paris Agreement, Portugal aims to lower greenhouse gas (GHG) emissions by at least 28% by 2030, compared to 2005 [5]. A crucial strategy to meet this objective is boosting the share of renewable energy sources (RES) to 49% of total energy consumption by 2030. This transition will be driven by greater electrification, wider adoption of renewables, and improved energy efficiency across multiple industries [6].

Between 2011 and 2022, Portugal saw a significant shift in its electricity generation capacity, with renewable energy sources expanding by 62.4%, while non-renewable sources declined by 40.3%, mainly due to the decommissioning of coal thermal power plants. Wind energy is widely distributed across the country, with an installed capacity of 5,671 MW, whereas solar power, despite being less extensive, experienced the most rapid growth in 2022, reaching 2,562 MW [2], [3].

The significant share of renewable energy in Portugal's energy mix highlights the growing role of wind and solar power in advancing the country's energy transition. While climate change may affect their efficiency, previous research suggests that solar photovoltaic (PV) potential will remain robust despite rising temperatures. On the other hand, wind energy could see a slight decline, with some regions experiencing a reduction in wind intensity by over 10% [7]. Nevertheless, wind and solar power remain crucial for decarbonizing Portugal's energy system.

However, producing and deploying renewable energy still comes with some environmental costs, such as impacts on land use and wildlife habitats [11]. For example, wind turbines can disrupt animal life through noise and pose risks to birds, while solar farms may require large areas of land and threaten bird populations [14].

The transition to renewable energy also brings up essential considerations regarding employment [15], [16], [17], [18], [19], with either positive or negative impacts varying from region to region [20].

Another relevant and widely discussed impact in the literature concerns landscape issues, which are generally perceived as negative [21]. Several authors have sought to understand how RES impacts the landscape and explore ways to mitigate such effects [22], [23], [24].

These landscape impacts, among others, play a crucial role in the social acceptance of renewable energy investments, including wind and solar energy [25], [26]. Social acceptance emerges as a key factor in the energy transition process and the implementation of RES projects [27]. Several factors may enhance this acceptance, with community benefits as a notable example, since providing tangible socio-economic benefits to local communities has significantly improved acceptance levels [28].

Additionally, social acceptance of wind and solar power projects seems increasingly relevant for developing such projects, given local opposition. In this context, a recent study developed by [29] has identified influencing factors such as "economic effects, impacts on residents and nature, attitudes towards the energy transition, trust in local actors and the planning process as well as social norms". Given the ongoing energy transition and the broad scope of influencing factors, social acceptance should not be disregarded since wind and solar power deployment is likely to increase, affecting a more significant number and larger local communities, requiring decision makers to be well informed regarding main concerns of local communities and how to address them to maximize benefits and minimize costs.

In this context, the present study addresses the following research question: what factors (benefits and/or costs) influence the perception (and the acceptance) of new investments towards a sustainable energy system? To address this issue holistically, a system thinking approach is undertaken to portray different stakeholders' perceptions and interactions.

It is important to note that this study adopts a more specific perspective, analyzing the perception and acceptance of the local population. This factor is particularly relevant, as the literature suggests significant differences between national and local acceptance levels of RES [30].

II. METHODOLOGY

The present study resorts to the system thinking field of knowledge to portray and assess the links of new investments in wind and solar power to reach a more sustainable energy system using a systemigram. A systemigram [31] is a tool that enables the conversion text, which in this case, is based on existing literature, to a visual representation of a complex system, in virtue of the diversity of stakeholders, impacts (socioeconomic and environmental), and their interactions, contributing towards an improved understanding of the same. As mentioned, the impacts and stakeholders constitute the system's key elements and become its central nodes. These nodes are then interconnected by arrows that depict the relationships between them. The interconnections are associated with verbs and the nodes to nouns; together, they tell a narrative. According to [32] a system is considered "well-mapped" when there is a "logic flow" to the story from the beginning to the end. The present work follows the steps from [32] to ensure this, namely:

- Definition of the system of interest: it is the first node of the system, at the top left; meanwhile, the last node is located at the bottom right. The interpretation is made in this direction (from top left to bottom right);
- The nodes and connections added in between the extremes are designated as scenes that flow from and to the main nodes telling parts of the story, where the nodes represent key elements of the system (nouns) and the arrows represent the dynamics/relationship (verbs), entailing a direction (i.e., from one node to another node);
- The connections should not be crossed over, and the systemigram should be composed of 15 to 25 nodes;
- Before this, a literature review focused on wind and solar power and stakeholders (e.g., local community).

The systemigram is built upon the relationships portrayed in the existing literature. So, before using this tool, a literature review was conducted on community acceptance and RES externalities in the Scopus database. The search for papers resulted from the combination of the following keywords for each energy alternative across title and abstract fields:

- Wind Farms: "wind power" AND "environmental impacts" OR "socioeconomic impacts" OR externalit* AND "local municipality" OR "local community" OR stakeholders.
- Solar Farms: "solar power" AND "environmental impacts" OR "socioeconomic impacts" OR externalit* AND "local municipality" OR "local community" OR stakeholders.

This yielded a total of 132 – 81 for wind and 51 for solar power – in English (including research articles and review papers). A set of exclusion criteria was then applied to eliminate studies deemed out of scope (e.g., considering other sectors such as electric vehicles or other energy alternatives such as biomass) without access to full paper. This excluded a total of 89 journal articles. Additionally, a snowball sampling technique was applied to include studies considered relevant but not captured initially, reaching the final number of studies considered. The search, which referred to the abovementioned research string, was conducted in January 2025 and resulted in 58 works for assessment. This initial effort resorted to Systemitool software, developed by [31], [32]. The obtained results and detailed scenes are presented in Section III.

To the best of our knowledge, this methodology has been applied in a limited number of studies within the energy sector. However, it has already enabled a comprehensive analysis of key matters, such as the drivers of decarbonization [34], policies promoting electric and low-emission vehicles and their associated impacts [35], as well as changes in the electricity system and their implications, as a result of the interconnection among various components of the renewable energy electricity sector in Indonesia [36].

Among the studies that adopt a Systems Thinking perspective to analyze the energy or renewable energy sectors, one notable work [37] stands out as closely aligned with this research's objectives. That study examines impacts and externalities, such as changes in employment associated with the operation and implementation of RES. It includes an analysis of community acceptance (of RES) and a node labeled "Organizations and Institutions," representing an important step toward incorporating key stakeholders into the system.

However, the present study differentiates itself by disaggregating stakeholders and emphasizing the role of energy justice in accepting RES, leveraging the Systemigram methodology to enhance a holistic analysis that integrates a broad range of factors, particularly relevant in the context of renewable energy transitions.

III. RESULTS AND DISCUSSION

Figure 1, in Appendix, illustrates the nodes and relationships within the system. It is important to note that this study does not delve into all the relationships depicted in the system. Such analysis would require a level of depth beyond the scope of this work. Therefore, the focus is placed solely on the stakeholders and factors highlighted in green, with arrows marked by a darker shade instead of the remaining system in grey. Figure 1 in Appendix, also highlights local community stakeholders and RES externalities relevant within the scope of the R3EA Project, though different stakeholders' roles are recognized in the systemigram. In this sense, nodes in Figure 1 are emphasized in color versus the muted grey background nodes and links. Therefore, although the scope of R3ES refers to the new investments in RES to attain a more sustainable energy system, the present study depicts only some focal aspects at the local level. For instance, while it is recognized that governmental authorities, at the national level, establish guidelines and tools to implement RES projects that determine the context in which local authorities act, the highlight is on local community interactions, as illustrated in Figure 1. Considering the space restrictions, this example reflects the complexity of the interactions and the need to establish an approach to present the results.

Additionally, as an introductory approach to the system thinking diagram, the representation of the system is more generic. Thus, initially, it did not delve into or assess closed-loop diagrams (CLD) and their nature in detail.

The node "New investment W/S" refers to investments in wind and solar energy, representing the system of interest. On the other hand, "Sustainable W/S" pertains to the purpose, which is to achieve a sustainable energy system. Here, this system resorts to using RES to promote environmental and social aspects, namely the reduction of environmental impacts, while contributing towards accessibility, affordability, security, and equitable distribution of resources.

A. Visual Impact

One of the most frequently mentioned and extensively studied impacts of investments in wind and solar energy facilities in the literature concerns the effects of these technologies on the landscape. Consequently, this relationship is represented with an arrow indicating that wind and solar investments affect the landscape. Landscape alterations are often the most significant factor influencing local acceptance [30]. High public sensitivity to this issue may increase the total cost of the electricity system, namely by increasing the levelized cost of electricity of the system (LCOE) [38], since sensitivity to the visual impact of onshore wind farms restricts construction areas by excluding scenic lands, significantly reducing available land for RES development. This, in turn, limits potential capacity and increases reliance on other sources, which could drive up costs due to additional infrastructure or lower efficiency.

Beyond directly influencing local perceptions and acceptance levels, landscape changes may also have an impact through fluctuations in property values. While local services and infrastructure play a more decisive role in property pricing [39], [40], the natural landscapes can increase housing prices [39], [41]. These price variations could indirectly influence public perception and, ultimately, the acceptance of wind and solar farms. Moreover, the focus on landscape, as an example, denotes the need to envision the direct and indirect nature of its impact, i.e., the visual impact of the wind turbine itself and the impact that the alteration of a pristine landscape might indirectly induce on other commodities, such as housing prices.

Despite being predominantly perceived as having a negative impact, several mitigation strategies may help to alleviate the consequences of wind and solar investments on landscape (which consequently reduces the likelihood of local acceptance). It is important to integrate landscape issues early in the planning process to ensure that local values and concerns are considered and respected [42], in addition to employing technology to minimize noise pollution associated with wind turbines and repowering existing installations with modern, less intrusive structures [43]. Developing outdoor recreational spaces around renewable energy sites may mitigate the impact, although this measure is generally considered less effective [43]. In this regard, it is essential to highlight that measures aimed at minimizing visual impact tend to be more effective in improving public acceptance than compensatory measures [43].

B. Noise & shadow flickering effect

Public debate on acceptance also tends to focus on other environmental issues, as illustrated in Figure 1. A recent review on externalities from wind power projects, developed by [44], has indeed emphasized the relevance of environmental impacts, namely of visual impact, followed by noise disturbance and, to a much lower extent, shadow flickering effect. Regarding noise disturbance, found that noise exposure from wind farms results in annoyance, which can be aggravated by the shadow flickering effect. In the proximity of the wind farms, the influence of noise exposure on other health effects, such as increased stress or sleep disturbances, has been inconclusive since other contextual aspects also seem to have an influence (e.g., planning and decision process) [45]. Recent studies emphasized the relevance of the assessment and compliance of safety distance regulations to ensure adverse effects of noise and shadow flickering are averted or minimized prior to wind farm development, contributing to overcoming the local community's mistrust and opposition by addressing their concerns (e.g.[46]). Hence, health externalities from environmental impacts, such as noise, should be further considered within the scope of social impacts from wind and solar power investments and its influence on local community perception (e.g. [47]).

Apart from these mitigation efforts, it should be noted that acceptance is also influenced by other factors, some of which may contribute positively to it, such as community benefits, which will be explored in the subsequent discussion.

C. Community benefits

In contrast to visual impact, prior studies have mentioned that attributing community benefits (e.g., rental for communal land use and project ownership or shareholding) might sway local perceptions towards acceptance (e.g., [48]). Therefore, the interconnection between the nodes is labeled "improves" in the presented systemigram, as illustrated in Figure 1.

Yet, this result should be viewed carefully since, as recognized by [47], although economic benefits are relevant, they may not be consistent predictors for the acceptance of wind farms. This denotes the case-specific nature of this relation and the fact that it may not seem to be a consensual issue, as initially thought. Moreover, the literature points towards a connection of community perception with institutions, such as the role of local municipalities and energy justice, for a better understanding of the attribution of community benefits and the context that might lead to opposition to new investments (e.g., [49]). Nevertheless, this factor has also been pointed out as a driver for a just and fair process that leads to the acceptance of a more sustainable energy system [43]. Yet, some authors suggest that community funds must be communicated upfront to avoid being seen as suborn towards acceptance (e.g., [47]) and formalized compensation schemes [49].

D. Energy justice and social acceptance

This issue has been increasingly focused in the context of energy transition. In this sense, and following the literature, the interconnection in the systemigram is designated "conditions", reflecting both the negative impact the injustice can have on perception and the positive role institutions can play in overcoming this negative perception encountered in the existing literature. The perception of the lack of distributional justice, i.e., the equal distribution of benefits and the uneven geographic distribution of wind farms, has been claimed as the source of both local and municipal opposition in Sweden [49]. Yet, as previously mentioned, the latter could be relevant in promoting information and awareness among the local community regarding the benefits and costs of developing new investments and promoting a transparent and straightforward process. These aspects are among the good practices that could contribute to overcoming the community opposition while promoting their acceptance, as mentioned by [43]. Besides distributional justice, procedural justice, which urges public governance at different levels to promote "public involvement, information, consultation and participation" in wind power development, has also been mentioned as a pathway to acceptance [50]. Local communities can reach social acceptance of wind farms through differing types of communities and benefits by combining procedural and distributional justice, resulting in win-win situations. For instance, according to [51], a small wind farm located in the close vicinity of a residential area can still benefit from local acceptance when there are high participation rates in project planning combined with a just and equitable distribution of benefits at the local community level (project ownership). Similarly, community acceptance can also be reached with other communal benefits (e.g., parks, libraries) for large wind farms located in the vicinity of residential areas when the local community is highly involved in the planning process [51].

E. Strength of the effects

In a systemigram representation, the links (arrows) between each node may also convey the "strength" of the effect, i.e., denoting the positive or negative effect elements of the system exert on each other. In this sense, consider an arrow from node A to node B exerts a positive (+) change or change in the same direction from A to B (both experience an increase/decrease). On the other hand, a negative (-) effect entails a change in opposite directions [52], [53]. The present study portrays the polarity of focal interconnections, with examples discussed earlier that are emphasized in color against the grey background in Figure 1.

As illustrated in Figure 1, new investment seems to affect the landscape, altering the community perception. To include the "strength" of the effect, the present study has adapted from González et al. [37] approach by identifying the most common impacts across the literature review (mentioned in more than three studies gathered according to preestablished keywords) and assigning them according to the impact sustainability dimension (e.g., environmental or socioeconomic). The link polarity was discussed, and coherence was checked with the reviewed literature and system thinking approach. Additionally, based on [54], this paper considers a dotted line that stands for 'weaker but relevant links,' which is aligned with the indirect nature of externality, versus the full line that stands for the strong links, aligned with the direct impact of new investments. The next example focuses on the landscape impact in Figure 1, which shows direct and indirect links between nodes, i.e., full and dotted lines, respectively.

Although concerns with energy security seem to accommodate discomfort with RES at the national level, at the local level, the proximity to the wind farm is very relevant, emphasizing visual impact, and might become a serious barrier for RES in Germany [21]. This result highlights the relevance of the context (national vs local) and the different perspectives, according to sociodemographic profile, such as education and age in terms of RES technology perception. The present study looks to portray a local and regional perspective. Therefore, based on the literature review example, the arrow between new investment and landscape is a negative (-) full line in Figure 1. This means that the increase of new investment W/S deteriorates the landscape.

Furthermore, [38] claims landscape preservation in Great Britain limits onshore wind deployment by making less land available, increasing costs. This increase might have a negative influence (-) on both the perception and the acceptance of the project, possibly contributing to a decrease in onshore RES if disregarded by policymakers, which might require further research in terms of local community impact ([38]). This example denotes the complexity of the interactions between sustainability dimensions since, despite landscape preservation, economic aspects (increasing costs) decurrent from lack of space may condition community perception and project acceptance. Yet, repowering and offshore and housing solar PV have been considered possible alternatives, although further research is also required to understand their impacts better. Additionally, Figure 1 highlights that the alteration of the landscape might also negatively affect (-) other nodes, such as housing prices, as new investment in W/S increases. While the view of natural landscapes increases housing prices, investment in RES, such as wind parks, affects housing prices negatively [55]. This study argues that the negative impact on housing prices might also affect community perception by its proximity and ultimately may contribute to opposing RES investment because of the depreciation of housing prices (dotted line). According to [55], the close presence of wind turbines (<1km) could lead to a reduction of prices between 3–6%, though the impact of its presence could be felt up to 3 km. Additionally, although energy justice and social acceptance tend to go in the same direction, they might imply different meanings. For instance, energy injustice influences acceptance by decreasing it. Meanwhile, local municipalities influence energy justice positively, contributing to increased acceptance, even though they share the same polarity sign. Yet, these results should be cautiously assessed given the results from the keyword string, which could pose a caveat to the present study.

Overall obtained results show, based on the systemigram, that the relationship between new investments and a more sustainable energy mix is a complex system, with direct and indirect relationships, such as those captured with visual impact, influencing perception directly via alteration of the landscape or as an externality affecting property prices. Ultimately, these elements shape the acceptability of new investments, along with the perspectives of different stakeholders. According to the identified interconnections, although community benefits may influence acceptance and contribute towards a sustainable energy system, promoting energy justice through different stakeholders has been emphasized. In this sense, local authorities play an essential role. Moreover, the prior assessment of environmental impacts, ensuring stakeholder participation in the process, might be relevant for the acceptance and the advancement of a just energy transition. This way, it is possible to consider local community concerns for developing mitigation strategies regarding wind and solar power investments.

IV. Conclusion

The study proposes a graphical representation of the relationship between new investments in wind and solar power and a more sustainable energy mix through a systemigram used to depict complex systems. The relationships depicted in the system have been reported in the literature and, as such, depict the context and perspective of local communities where RES was developed. The assessment of existing literature enabled the identification of the main stakeholders and relevant interconnections. However, the present work does not reflect the fieldwork stakeholder perspective. In literature, the exact impact could be viewed as a problem and, simultaneously, a possible solution to developing new investments, particularly if viewed through an energy justice lens. Therefore, the mapped diagram sheds light on the interconnections and enables policymakers to view them holistically, and this is essential because of the many factors and people affected. Local acceptance is one of the most critical factors for successfully implementing renewable energy projects. Thus, further research is warranted regarding additional analysis of the nature of these interconnections, if positive or negative, and how to promote mitigation of adverse impacts while maximizing positive impacts for local communities, as well as to determine barriers and opportunities from a local stakeholder perspective.

There is a need to engage different stakeholders further in identifying and assessing impacts to develop common strategies that promote new investment in wind and solar power. For instance, in the context of the energy transition, it is essential to promote new investments by simplifying steps, such as licensing, that constitute bottlenecks in project development; here, local and national institutions could play a key role in removing administrative barriers while integrating different stakeholders (e.g., [56]). However, it is necessary to explore these interconnections further.

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V. APPENDIX

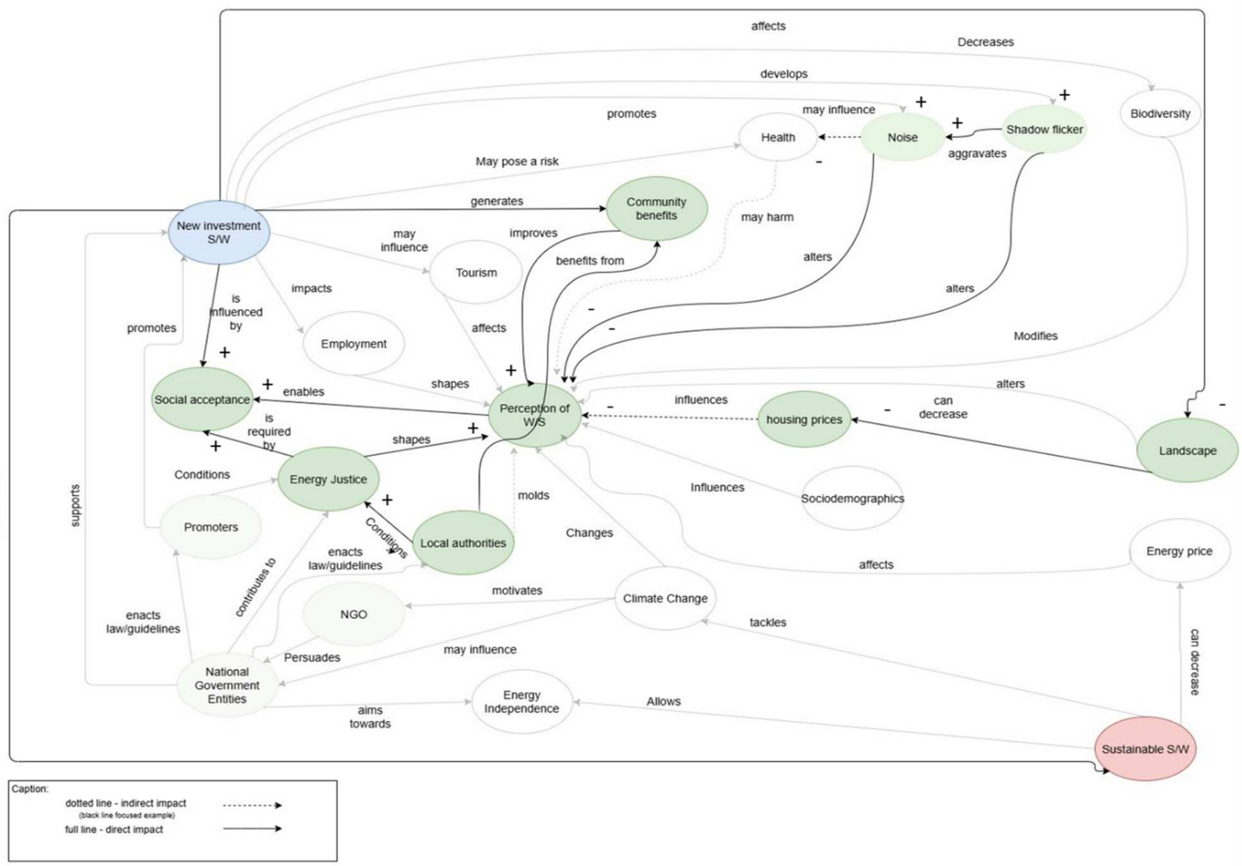

Figure 1 - Graphical representation (Systemigram)